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**A SURVEY AND EVALUATION OF CHEMICAL WARFARE
AGENT-DECONTAMINANTS AND DECONTAMINATION**

15 OCTOBER 1984

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for

**Aeromedical/Casualty System Program Office
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PREFACE

The USAF Aeromedical Division (AMD) has tasked Computer Sciences Corporation's Engineering Laboratory (CSC-EL) at the National Space Technology Laboratories (NSTL) in Bay St. Louis, Mississippi to design, fabricate, and test prototype Contamination Control Areas (CCA's) to interface with Mobile Collective Protection System-Medical (MCPS-M). This task consists of the following three phases:

1. Decontamination alternative evaluation and system design
2. Functional mock-up fabrication, testing, and evaluation
3. Engineering model fabrication, testing, and evaluation.

This report, constituting deliverable items under phase one of the contract, is concerned with a literature search, evaluation, and initial selection of detoxicant and decontaminant systems. Also discussed will be methods of decontaminant application and selection of simulants.



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A SURVEY AND EVALUATION OF CHEMICAL WARFARE
AGENT-DECONTAMINANTS AND DECONTAMINATION

1. INTRODUCTION

The AMD has identified the need for mobile Medical Contamination Control Areas (MCCA's) for the Second Echelon Medical System (SEMS) where wounded personnel can enter for medical treatment. Before entering a Toxic Free Area (TFA), casualties must be thoroughly decontaminated. Although the present concept for an MCCA has been generally accepted, more development and refinement are needed in the areas of decontamination and processing, because current decontamination methodologies are too cumbersome, time consuming, and inefficient.

The purpose of this report is two-fold:

- a. To review literature and investigate new decontamination technologies, which will lead to identifying more effective detoxicants and decontaminant systems
- b. Selection and development of more promising application methods for decontamination processes which will meet the following AMD decontamination criteria:
 - Protective clothing should be decontaminated to below the allowable levels, which will result in "no effect" levels on skin as indicated in table 1. Allowable dosages received by personnel are also listed.
 - The decontamination process must be completed within four minutes.
 - Ability to remove or mask the reaction mixtures and agent residues, while maintaining the integrity of the equipment and MCCA.

TABLE 1. ALLOWABLE AGENT LEVELS

<u>Agent</u>	<u>Maximum Liquid Remaining on Skin of Casualty (mg)</u>	<u>Maximum Dosages Received by Personnel (mg min/m³)</u>
GB	0.003	0.05
GD	0.003	0.01
HD	0.02	0.2
VX	0.003	0.002

- The decontamination reaction and end-product will be relatively non-toxic.
- The decontamination process will cause no harm or present health hazards to involved personnel.
- A single decontaminating system will be used for all agents and situations.
- An acceptable stoichiometry and logistics will be developed (i.e., relatively small amount of decontaminant to be effective for decontaminating agents).
- The detoxicant/decontaminant will be readily available and easily applied at a reasonable cost.
- Chemicals utilized will have a minimum storage life of 10 years.

2. OBJECTIVE

The overall objective of this contract is to develop methodology for safely removing casualties from their contaminated protective clothing for medical treatment. Therefore, the developed decontamination process must be adequate, not only to detoxify agents, but also to prevent agent vapor

desorption from contaminated clothing. In addition, the decontamination process must not damage the integrity of the MCCA system and must be effective against any agent.

3. APPROACH

Ideally, decontaminants will effectively destroy, neutralize, remove, or irreversibly bind the various agents in vapor, aerosol, liquid droplet, and thickened form. Although numerous attempts have been made in the past 60 years to develop an ideal decontamination process for chemical agents, there seems to be no practical system available to meet ADM's decontamination criteria listed in the introduction of this report. For this reason, considerable effort was expended in an attempt to find new concepts to meet the objectives of this contract. These new concepts, when applied alone or combined with promising decontaminants, should quickly and completely decontaminate litter casualties.

One of these new concepts involves coating casualties who are still in Mission-Oriented Protective Posture (MOPP)-level 4 gear, with a thin layer of a fast-setting polymeric film or other binding and containment material following mechanical application of a detoxicant/decontaminant. The polymeric film is intended to completely seal residual agent or end-reaction products of the agent and detoxicant onto the clothes. The advantages of this type of "cocoon" coating are multiple:

- The coating should seal both unreacted agents and chemical residues.
- The coating should prevent desorption of absorbed agents.

Shortly after polymer application, the protective clothing can be cut away by electric scissors and the casualty removed safely for medical assistance; the removed protective gear can then be disposed of immediately.

The data and information in this report were collected in two ways. An extensive literature search was conducted to identify and evaluate all

previously known agents-decontaminants, fast-setting polymers, or binding, and containment materials; telephone inquiries were made to industries concerning decontamination technologies. Decontamination approaches investigated include removal, detoxification, inactivation, and suppression. The following data bases and sub-bases were searched:

- NASA/RECON (1968-1984)
- Lockheed DIALOG
 - AGRICOLA (1970-1984)
 - BIOSIS PREV. (1969-1984)
 - CHEMICAL ABSTRACTS (1968-1984)
 - CHEMICAL INDUSTRY NOTES (1974-1984)
 - ENVIROLINE (1971-1984)
 - EXCERPTA MEDICA (1975-1984)
 - FEDERAL RESEARCH PROGRAM (1982-1984)
 - FOOD SCIENCES AND TECHNOLOGY (1969-1984)
 - NTIS (1964-1984)
- DTIC (1918-1984)

After completing the computer literature information search, hundreds of abstracts were obtained and reviewed. Complete copies of particularly relevant publications gleaned from the abstracts were obtained for more detailed study. A list of the title, author, date of publication, AD number, and a synopsis of each selected article is appended to this report (Appendix A). The telephone inquiries with pertinent information have also been appended (Appendix B).

4. MILITARY PROTECTIVE GEAR

The military protective gear includes mask, hood, clothing, gloves, and overboots. A diagram of a typical protective gear is presented in figures 1 to 5. Knowledge of the characteristics of this gear is essential if proper detoxification/decontamination procedures are to be developed. Therefore, each subitem of the protective gear will be described in detail in the following subsections.

4.1 The Mask.

The mask provides protection for the user's face, eyes, and respiratory tract from vapor and aerosol agents. The major components of the mask are the face piece (generally known as the mask), eyelens outserts, a voicemitter with a rubber cover, and one or two filters (depending on the model). When the mask is worn, the filter material contained within the filter elements remove agents from the ambient air. The decontaminated air then passes into the mask and is inhaled by the user. Exhaled air is discharged through an outlet valve located at the chin position. The mask is designed to effectively protect the user from agents, but it does not protect against ammonia vapor and carbon monoxide. The mask is made of natural rubber with rigid and clear plastic eyelenses as shown in figure 1 (1).

4.2 The Hood.

The hood is used to cover and protect the user's head and neck. The hood is made of butyl rubber and shown in figure 2.

4.3 The Clothing.

The clothing (shown in figure 3) is a two-piece suit consisting of a coat and a pair of trousers. The coat has a short standing collar and a full-length zippered opening covered by a double protective flap, elastic sleeve closures, and two outer pockets located at chest level. The trousers have two pockets, a fly-front with protective flap, adjustable waist tabs, suspenders and belt loops, and zippers located on the lower outside section of each leg. The clothing material consists of an outer layer of nylon-cotton coated with water-repellent chemicals, and an inner layer of polyurethane foam bonded to a nylon tricot fabric impregnated with charcoal. The water repellent chemicals consist of an aluminum salt of a saturated carboxylic acid (such as format, acetate, palmitate, or stearate) mixed with refined mineral vegetable waxes (2). The clothing provides protection for the wearer against vapor, aerosols, and small droplets of liquid agents, and will afford at least 6 hours of protection from agent penetration (1).



Figure 1. CBR Protective Field Mask, ABC-M17 and Hood, ABC-M6A2

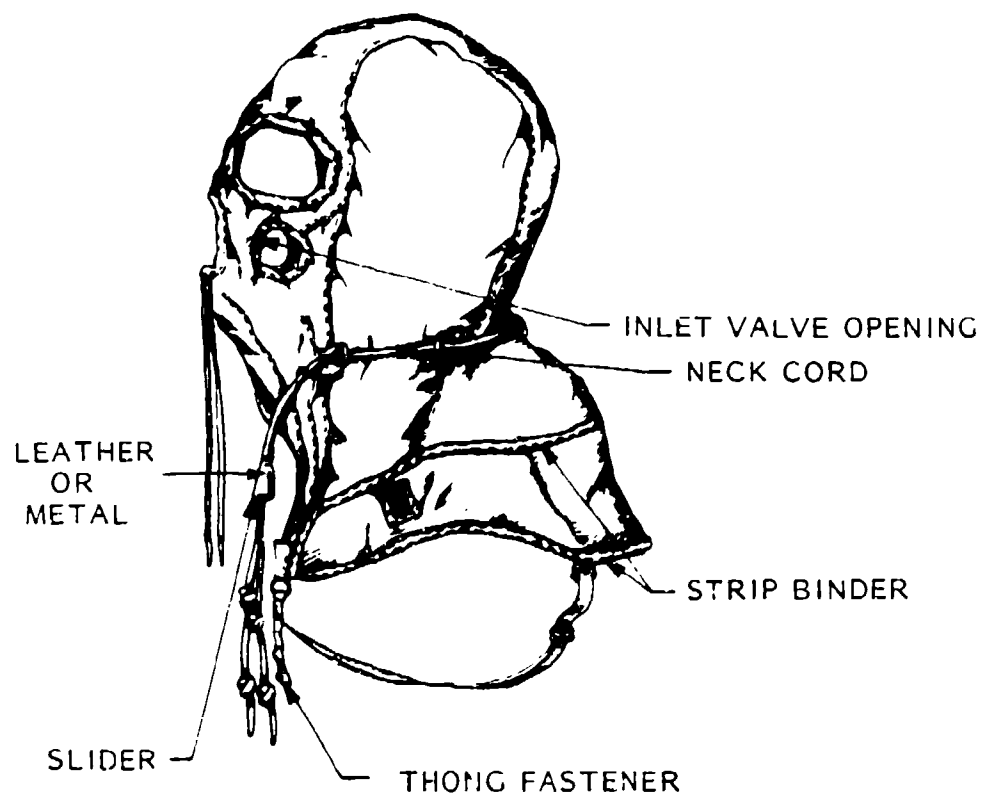


Figure 2. M6A2 Protective Field Hood



Figure 3. Chemical Protective Suit (Overgarment)

4.4 The Gloves.

The glove set (shown in figure 4) provides hand protection against vapor, aerosols, and small droplets of agents. The set consists of an outer glove to provide agent protection and an inner glove to assist in absorption of perspiration. The outer 5-finger glove is made of an impermeable and unsupported butyl rubber, and the inner glove is made of cotton. Upon contamination, the glove set affords at least 6 hours of protection from agent penetration (1).

4.5 The Overboots.

The footwear covers (overboots, shown in figure 5) are worn over the standard boot and under the trouser legs to provide protection for the feet against exposure to all known agents in any form. The overboots are made of impermeable and unsupported butyl sheet rubber. Upon contamination, the overboots also afford at least 6 hours protection from agent penetration (1).

5. AGENT BEHAVIOR ON PROTECTIVE GEAR AND ITS RELATION TO DECONTAMINATION

Agents disseminated in vapor, aerosol, liquid, or thickened form can be transferred to the surface of protective gear by contact. Once protective gear is contaminated, agents begin to penetrate into the inner layers of the protective materials. The rate of penetration is dependent on the following factors:

- Concentration and amount of agents initially transferred
- Agent vapor pressure
- Agent forms (i.e., vapor, liquid, or thickened)
- Material properties
- Meteorological parameters.



Figure 4. Chemical Protective Glove Set



Figure 5. Footwear Cover, Chemical Protective (Overboots)

It is generally agreed that the higher the concentration or the larger the droplet size of agents that initially appear on the surface of a contaminated area, the faster the penetration rate. With respect to the agent form, it has been observed that neat agent can be absorbed by or penetrate into permeable materials very quickly--almost immediately upon contact with the material. Thickened agent droplets remain beaded upon most surfaces and penetrate slowly into the inner layer of the material. The penetration rate of an agent is also vapor pressure dependent--the higher the vapor pressure of an agent, the faster the penetration rate of that agent. For example, GD has much greater vapor pressure than VX and consequently, penetrates clothing more rapidly. If a large liquid agent droplet on the surface of clothing is exposed to a very low wind (0.5 to 1.0 mile per hour) until all of the agent is either evaporated or penetrated, the percent of penetration for VX and GD are 2% and 5 to 10%, respectively (3). It has been indicated that a normal type of woven fabric yarn can act as a multicapillary channel to suck in liquid agents from the surface of the fabric and transfer them to the bottom base layer (4). However, agent droplet volume must be sufficiently large enough to enable penetration through the inner layers of fabric. It was estimated at Edgewood Arsenal that the droplet size normally used in agent dissemination is not large enough to penetrate through conventional woven fabrics, but is soaked up by the multicapillary spaces between the yarn (4). Resultant toxic effects are actually a result of the emission, desorption, and penetration of vapor from these absorbed liquid agents.

Agent desorption or evaporation occurs simultaneously when agents begin to penetrate into material inner layers. The rate of agent desorption and evaporation depends on meteorological parameters (i.e., wind, temperature, humidity, etc.) and agent vapor pressures. The whole process of agent penetration, absorption, and desorption continues in clothing until all agent phases reach an equilibrium. This equilibrium is determined by the material absorption isotherm and the ambient meteorological conditions. It is generally agreed that decontamination processes become inefficient once agents have penetrated into the material inner layer (i.e., only the residual agent on the contaminated surface can be either physically removed or chemically

detoxified; penetrated agents will remain unaffected) (5). In addition, the use of thickened agent further complicates the decontamination process.

6. LITERATURE REVIEW

Since World War I, numerous materials and systems have been developed for decontaminating chemical agents from a variety of substrates. The principal agents of concern are listed below:

- Bis(2-chloroethyl) sulfide; HD (Distilled Mustard)--neat or thickened
- Isopropyl methyl phosphonofluoridate; GB (Sarin)
- Pinacolyl methyl phosphonofluoridate; GD (Soman)--neat or thickened
- O-ethyl S-2-diisopropylamino ethyl methyl phosphonothiolate; VX.

Current decontamination materials and methods can be generally classified into 3 categories: physical, biological, chemical. The following subsections which detail the literature information in each category were evaluated in order to determine the feasibility of decontamination application for the MCCA system.

6.1 Physical Methods.

Many physical approaches have been cited in the literature for decontaminating agents upon a variety of substrates. These approaches include the use of moist heat (6), dry heat (6), reverse osmosis (7), microwave (6), ultraviolet irradiation (8), ultrasonic vibration (6), molten salt incineration (8), laser (9), pyrolysis (8), infrared (6, 10), photodecomposition (11), sorbents (12, 13, 14), and containment materials (12). However, because of safety-considerations, from the above list, only sorbents and containment materials are potentially feasible for decontaminating wounded personnel, therefore, only these substances will be reviewed in this subsection.

6.1.1 Sorbents.

The use of sorbents as decontaminating materials for skin and other surfaces have been studied extensively since 1918. The results of these studies, repeatedly reported by many countries, generally agree that activated charcoal and Fuller's Earth (Surrey Finest) can be effective decontamination materials. Carbonaceous materials have been shown to be the best sorbents for gases because of their nonspecific nature, high sorption capacity, and fast sorption rates. For this reason, ASC whetlerite (a steam-activated bituminous coal impregnated with various metals) is currently used as filter material in all types of masks and collective protection devices, while Pittsburgh-activated charcoal is impregnated into clothing. It was reported (12) that charcoal powder (in the form of the commercial item, Nuchar), when gently dusted and rubbed onto the clothing surface (at a ratio of 2 mg/cm²), is effective in reducing agent concentration, while allowing time for litter persons to remove their protective clothing without exposure.

Fuller's Earth is a clay-type material and can nonselective decontaminate agents. Although Fuller's Earth may permit some insignificant agent desorption, the desorption problem can be minimized by using excess amounts of Fuller's Earth to retain the absorbed agent. The removal efficiency of Fuller's Earth for V and G from rabbit and human skin has been reported to be as high as 85 to 95% in laboratory studies, although somewhat lower results were obtained in field studies (13). Limited work has been conducted regarding the effectiveness of Fuller's Earth for decontaminating clothing. When used on porous or absorbent surfaces, the decontamination capability is generally less effective (13). Also, the sorption rate was noticeably much less with the thickened agents. The effectiveness of Fuller's Earth as decontamination material was subsequently confirmed (4, 13). After comparison studies of 22 domestic Fuller's Earth and two non-Fuller's Earth sorbent powders, it was reported that Fuller's Earth, regardless of its origin, is a very promising sorbent for removing agents. The report indicates that among non-Fuller's Earth materials, "Hazorb" is too slow in sorption rate, and silica gel (in the form of the commercial item, Comet) is very low in sorption capacity for agents. It was noted (4) that none of the investigated synthetic polymeric sorbents were as good in sorption capacity as Fuller's Earth. However, the

report indicates that alumina powder (100 to 140 mesh) has the highest sorption rate. Although silica gel (Comet) is low in sorption capacity, it is anticipated that silica gel can be a good sorbent powder if it is purified and activated. For this reason, Warsaw Pact nations have used powdered silica gel in their IMP Kit (13). It was reported (4) that when silica gel is combined with clay powder and formulated into a pressurized aerosol spray system, up to 80% of an agent can be removed from clothing without a rubbing in procedure.

Phenolic-type chemicals are known to hold G effectively by hydrogen bonding and are considered to be possible sorbent material(s) for agents. A preliminary test was conducted on nitro- or fluoro-phenol impregnated clothes to evaluate their retention effectiveness for agents: results indicated that these phenol derivatives effectively held G and V, but were inadequate against H (4).

Other sorbent formulations, such as aqueous charcoal slurries (23 to 28%) in water plus corrosion inhibitor and antifreeze compound, have been mentioned (7) for decontaminating agents, although promising results were not reported. A mixture of activated charcoal, thixotropic agent, dispersant, and antifreeze formulation, which can be easily sprayed over a contaminated surface, was suggested (15). However, no test had been conducted.

Sawdust, soil, silicone, coal dust, amine or sulfonic acid-containing polymers, organic and inorganic ion-exchange materials, and metal oxides have been mentioned for absorbing agents (15, 16) but have not been practical. It is interesting to note that after testing of several household products, it was concluded (17) that flour, followed by an after treatment with water (wet tissue-paper), can effectively remove all agents from freshly contaminated skin.

6.1.2 Containment Materials.

Potential candidate containment materials that can be used for decontamination by means of blocking and covering agents were tested (12);

12 compounds were recommended as the most promising candidates for future optimization testing. These compounds can be classified into four categories as indicated below:

- Natural products of gum-like materials
- Synthetic gum materials
- Latex systems
- Others (e.g., carbonwax, sorbitol, sugar syrup, etc.)

It was mentioned (18) that linseed oil paint and nitrocellulose lacquer coating have been successfully used for sealing agents onto contaminated surfaces, but these chemicals have never been used for large scale decontamination.

An ideal containment which was not mentioned in the literatures is a fast-setting polymeric system. However, this type of system is presently not commercially available and requires development.

It was also indicated (12) that among the three application methods tested (swabbing, fogging, and spraying), only the spraying method produced satisfactory results (i.e., ease of application, adequate coverage, film continuity, and containment efficiency).

6.2 Biological Methods.

The use of a cell-free enzymatic system, microorganisms, algae, and the state-of-the-art genetic engineering approach for decontaminating chemical agents has been cited (4, 19). Although this approach to decontamination may be very promising for general demilitarization of agents, it is not recommended for decontaminating wounded personnel because of relative difficulty in implementation.

A cyclodextrin type of complex containing many organic and inorganic materials might react with agents in a manner similar to complex enzymatic reactions. However, experimental data were not promising (4).

6.3 Chemical Methods.

Three types of chemical mechanisms--water/solvent or detergent wash, oxidation, and acid/base hydrolysis--have been used for decontaminating agents. Each type of chemical reaction will be systematically reviewed in the following subsections. H and V contain sulfur moieties that are readily subject to oxidation, while V and G contain phosphorous groups that can be hydrolyzed. Therefore, most decontaminants are designed either to oxidize H and V or hydrolyze V and G.

6.3.1 Water/Solvent or Detergent Wash.

A simple water or sea water wash serves two purposes:

- The removal of agents by mechanical force
- Slow hydrolysis of the agents.

The low solubility and slow rate of dissolution of agents in water are the two key factors that limit the agent hydrolysis rate. The addition of detergent to the water can increase the solubility of the agents. However, detergent solutions have been shown to be no more effective than water alone for H decontamination (20,21).

The use of an organic solvent wash as a decontamination method offers some advantage over water systems because agent solubility in organic solvents is generally much greater than in water. However, the main disadvantages of solvent washes are:

- Solvents do not destroy agents, but merely solubilize them
- Solvents may carry agents through the garment to the skin.

The most effective organic solvents being used for agent decontamination are JP-4, diesel oil, gasoline, kerosene, alcohol, and acetylene tetrachloride (20, 22).

After washing, water or organic solvents will contain the toxic agent and have to be collected for disposal. Also, they must be handled carefully to avoid spreading the contamination. These disadvantages are sufficient to exclude their application for the current project.

6.3.2 Oxidation.

A variety of oxidative chemicals have been used for agent decontamination. Each type of oxidative compound will be discussed in the following paragraphs:

- Hypochlorite salt (sodium or calcium)--These compounds are very corrosive. Chemical reactions involving these compounds are very violent and exothermic when the oxidant is in a solid phase. The reaction becomes easily controlled when the oxidant is in the form of an aqueous slurry. Bleach, ASH (0.2% calcium hypochloride in buffered water), and SLASH (0.5% calcium hypochloride, 1% sodium citrate dihydrate, 0.2% citric acid monohydrate, 0.05% detergent, and 98.25% water) all contain calcium hypochlorite and have been used for decontaminating agents from contaminated buildings, floors, the ground, and from various large-scale surface areas (23). Among these detoxicants, bleach is most extensively used for hazardous materials decontamination although it is relatively unstable.

Four forms of bleach are commonly used in these applications:

- A 5% aqueous sodium hypochlorite solution
- Supertropical bleach (STB) contains chlorinated lime and calcium hydroxide containing more than 30% chlorine

- High test hypochlorite (HTH) contains a solid form of CaClOCl plus calcium hypochlorite containing approximately 42% chlorine
- Dutch powder contains calcium hypochlorite and magnesium oxide

Among these detoxicants, HTH, having the highest percentage of available chlorine, is most often used for decontamination (7, 24). Although the chemical reaction rate for HD and bleach is relatively slow (7), bleach decontaminates V rapidly with a half life of 1.5 minutes at pH 10. STB has been used by the U.S. for large-scale agent decontamination, while chloride of lime (calcium hydroxide), containing at least 35% active chlorine, has been used by Russia for terrain and building decontamination (25). Sodium hypochlorite (5.25%) has been mentioned in the literature as skin decontaminant for V (26).

The effectiveness of Dutch powder for decontaminating all three agents (H, G, and V) has long been recognized by NATO countries and the U.S. (5, 13). It was reported (27) that Dutch powder can effectively decontaminate agents on vehicle surfaces. However, the subsequent cleaning process is hampered because the end-product mixture tends to adhere to the vehicle. For skin decontamination, the active ingredients of Dutch powder have been replaced by a less exothermic compound, MgOCaClOCl (13).

- Sodium dichloroisocyanurate (DCICNR or Fichlor CDB-63) and trichlorotriazinetrione (TCTATO)--These two compounds have chemical reactions similar to HTH. However, they are considered more aqueous stable and soluble than other chloramine salts (such as chloramine -B, T, etc.), and have been used for laboratory-scale decontamination of all agents on painted surfaces (7). After 2 weeks storage at room temperature, it was reported (28) that DCICNR or TCTATO impregnated clothing can be effectively

protected against HD attack. However, these chemicals destructive capability toward G and V was not evaluated.

- Chloramine-B and chloramine-T--These two compounds, when compared to HTH, are very stable, water-soluble, and less corrosive to skin although they are relatively expensive. Nevertheless, they have been incorporated into the M258/258A1 decontamination kit to detoxify HD and V (7, 16). By mixing the chloramine-T with a VX simulant, malathion(diethylmercaptosuccinate S-ester with o,o-dimethyl phosphorodithioate), in a surface activated displacement solution II (SADS II), it was reported (29) that up to 99.5% of the malathion was destroyed within 1 minute in the temperature range of 5° through 45° C. This report shows that chloramine-T outperformed all other tested chemicals in SADS II--hypochlorite salt, persulfate salt, perborate salt, formaldehyde, and sodium hydroxide. Further testing was conducted by spraying the chloramine-T-SADS II solution on a malathion-contaminated painted aluminum surface. It was found that approximately 68% of the malathion was destroyed (29). In Russia, DT-1 (monochloramine-B or sodium benzene sulfonchloramine) in dichloroethane has been practically used for H decontamination of skin, clothing, and equipment.
- Dichloramine-B and dichloroamine-T--These two compounds are water insoluble and are unstable when exposed to sunlight and moisture. They are readily soluble in many organic solvents in which H and V are soluble and thus have been used for decontaminating these agents (7). In Russia, DT-2 (dichloramine-B or dichloramide of benzene sulfonic acid) in dichloroethane has been used for decontaminating H on metal surfaces; DT-2T (dichloramine-T or dichloramide of p-toluene sulfonic acid) in dichloroethane has been used for decontaminating H on wooden and metal surfaces; DT-6 (hexachloromelamine or hexachloramino-S-triazine), DTS-CK (aqueous slurry of di-tribasic salt of calcium hypochlorite with sodium silicate), ethanolamine, solution I (8% solution of DT-6 in dichloroethane plus 10% DT-2 or DT-2T in

dichloroethane), solution II (mixture of 2% sodium hydroxide, 5% monoethanolamine, and 20% NH_4OH), and other similar formulations (such as EF 1-1, EF 1-2, and EF 1-3) have been employed by Russia as decontaminants (25). Solution I has been reported to be good for H- and V-gases; solution II is good for G; DTS-CK is employed as a general-purpose decontaminant (21, 25). Other compounds belonging to this group include the following:

- N-chlorosaccharin
- N-chlorosuccinimide
- N-chlorophthalimide
- N-chloroacetamide
- Bis-(2,4,6-trichlorophenyl) dichlorourea
- N-(2,3,6-trichlorophenyl) N-chlorobenzamide
- DANC: 7% solution of 1,1-methylene bis-[3-chloro-5,5-dimethylhydantion (S-210 or RH 195) in tetrachloroethane]

N-chlorosaccharin in pH 8.6 aqueous solution was predicted to have shortened the half life of V to 10^{-4} seconds, but low water solubility among other factors has actually prevented application of this compound (7).

XXCC3, which is a combination of CC2 [Bis-(2,4,6-trichlorophenyl) dichlorourea] with 10% zinc oxide stabilizer (a solvent-binder type substance), has been incorporated into ABC-M13 decontamination kit and impregnated into clothing materials for agent protection, especially versus H and V (28). XXCC3 was further tested for use in a microencapsulation concept. Preliminary results indicated that 0.30g of ethyl cellulose

microcapsules which contained 75% of XXCC3 would deactivate 87% of neat H (0.02g) in less than 1 hour (28).

DANC has been used extensively in the past for decontaminating agents. However, the high toxicity of tetrachloroethane and its corrosive effect on paint surfaces and rubber limit the use of DANC. In addition, DANC is ineffective against G.

- Chlorine and chlorine dioxide--The chemical reaction of these two compounds is very rapid and strongly exothermic hence, suited for large scale demilitarization of agents. Because of the highly corrosive nature of chlorine and the explosive property of chlorine dioxide, their use as decontaminating agents is quite limited.
- Potassium permanganate--This compound reportedly detoxified V at a 20:1 molar ratio (7). However, the rate of destruction was not determined. It was reported (18) that 2.5% potassium permanganate solution did not effectively decontaminate H.
- Potassium peroxydisulfate--This compound combined with a silver ion catalyst has been suggested for the decomposition of V, but experimental work has never been conducted (7).
- Chromic acid--Chromic acid in concentrated sulfuric acid solution reacts readily to oxidize H completely (18), but this solution is extremely corrosive.
- Ozonated air--It converts H into the sulfoxide, but its use is not practicable because the amount and concentration of ozone generated by commercial ozonators is inadequate (18).
- Metallic peroxides, benzoyl, and hydrogen peroxides--These compounds react slowly or not at all with H, and are too inert for practical use (18).

- N-bromo organic compound--In an attempt to search for a new oxidant which is noncorrosive and nontoxic, 3-N-bromo-4,4-dimethyl-2-oxazolidinone (NBO) was found to be very effective for agent decontamination (30). In a 0.03M NBO solution containing the surfactant cetyltrimethylammonium chloride (CTAB) at pH 9.5, it was found to be effective against all agents. Unfortunately, logistical burdens restrict the use of this formulation (e.g., it requires 6 to 18 moles of NBO to destroy one mole of VX. In addition, the low solubility of NBO in water has actually limited detoxification capacity of agents).
- Catalytic free radical systems--Catalytic oxidation is probably not feasible at room temperature within the present state-of-the-art (4, 7). It was further indicated (4) that other catalysts, such as silicones, silazanes, metal salts, and organo-metallic compounds can not accelerate the reaction rate to meet the stringent criteria delineated in this report's introduction.
- Ionic polymers containing sulfuric or phosphoric acid functional groups--These polymers were reported not to be effective against agents (28).
- Miscellaneous Oxidants--Perchloryl fluoride (ClO_3F) and dinitrogen tetroxide (N_2O_4) were developed and tested (31); results indicated that none of these new oxidants can effectively decontaminate agents. Sodium chlorite and sodium chlorate were tested for their decontamination ability toward H, but were found no more effective than bleaching powder (18). Polyacrylamidoxime and a unknown product formed by reaction of chloroacetylhydroxylamines with alkyl dimethylamines showed very good reactivity with DFP and paraoxon (agent simulants), but no detailed data were given (32).

6.3.3 Hydrolysis.

Chemical hydrolysis reactions can be classified into two types: alkaline and acid. Acid hydrolysis is less important for agent decontamination because the hydrolysis rate is slow and acid catalysis is rarely observed. For this reason, the detailed hydrolysis mechanism for agents in acid solution will not be discussed. Alkaline hydrolysis is initiated by the nucleophilic attack of the hydroxide ion on the phosphorus moiety. The hydrolysis rate is dependent upon the chemical structure and reaction conditions such as pH, temperature, the kind of solvent used, and the presence of catalytic reagents. The hydrolysis rate increases sharply at a pH higher than 8. Since hydrolysis is primarily catalyzed by the hydroxide ion under alkaline conditions, the hydrolysis rate is proportional to the concentration of hydroxide ion. In general, the hydrolysis rate increases tenfold with each additional pH unit.

Temperature also influences hydrolysis rates. It has been estimated that the rate increases about 4 times for every 10° C temperature rise. Because the type of solvent used also greatly affects the hydrolysis rate, surveyed decontaminants will be discussed in three solution classes: aqueous, partially aqueous and non-aqueous:

- Aqueous solutions--The hydrolysis rates for G and V are proportional to the concentration of hydroxide ions, while for H, the hydrolysis rate in any solvent solution is essentially the same as that in water alone. It was reported (7) that hydrolysis rates for GB and V are less than 1 second and 0.2 hour respectively at pH 13 and at ambient temperature. However, the actual rate will be slower because the solubility of the agents in water is not great.

Many bases have been studied and used for agent decontamination. Although sodium hydroxide and ammonium hydroxide have been mentioned for hydrolyzing H, their effectiveness is not known because of contradictory results (7, 21). Also, these bases had been reported as nonuseful for large-scale decontamination of H. In contrast to H, aqueous sodium hydroxide has been used in a

standard method for the decontamination of bulk G from munitions and occasionally for V (7). Sodium hydroxide (caustic soda or soda lye) and potassium hydroxide (potash lye or potash solution) have been used for equipment and terrain agent decontamination in both U.S. and Russia. Sodium carbonate (washing soda), which is less corrosive, has been used for destroying GB. The half life of GB in aqueous solution was reported to be 8.5 seconds (7). Again, the low solubility of GB in solution hampers its decontamination application.

A number of other strong basic solutions have been mentioned for agent decontamination. These solutions include aqueous ammonia (water containing up to 25% ammonia with or without additional alkali), trisodium phosphate, and sodium silicate. Aqueous ammonia (weak solution with no precise concentration) has been used for skin, clothing, and personal equipment decontamination by Russia (25). Gaseous ammonia has also been mentioned for clothing decontamination.

In an attempt to develop a new water-based decontamination formulation (noncorrosive, nontoxic, and logistically acceptable) to be effective against all agents, several novel nucleophiles have been synthesized and tested for their destructive capability toward agents. The test results indicated that micellar aldoximes (1-n-dodecyl-3-pyridinium aldoxime salts) at a pH around 9.5 are good reagents for destruction of G and V, but are ineffective against H (24, 30). All other novel nucleophiles, such as cetyldimethyl (2-hydroxyethyl) ammonium bromide, cetyldimethyl (2-mercaptoethyl) ammonium bromide, and N-methyloctanohydroxamic acid were found to be ineffective in agent decontamination (30).

A number of metal ions especially those of copper (II), uranium (VII), zirconium (IV), thorium (IV), and molybdenum (VI), have been observed to increase the hydrolysis rate of agents in water. Some metallic salt solutions, which are less corrosive, have been experimentally tested for their feasibility

in decontamination of agents, [e.g., uranyl nitrate with tetramethylethylenediamine, and uranium-dioxy-bis-(5-sulfo-8-hydroxyquin-oline)]. However, preliminary test results indicate that these chemicals are too slow for agent detoxification (7).

It was suggested (33, 34, 35) that bidentate nitrogen donor ligand to Cu (II) with water and/or hydroxy ligands occupying the remaining positions in the square-planar first-coordination sphere, are more effective as hydrolysis catalysts than the corresponding hydrated metal ions. The most effective ratio of amino nitrogen to Cu (II) was found to be 2:1. It was indicated (33) that the half life of GD in 1:1 ratio of Cu (II): tetramethylethylenediamine (TMEDA) is 1.0 minute at pH 7.0. Although several diamine - Cu (II) complexes including di-u-dihydroxo-bis-(N,N,N',N'-tetraethyl-ethylenediamine) dicopper (II) diperchlorate have been postulated for incorporation into polymeric resins for agent decontamination (33), experiments were not carried out.

- Partially aqueous solutions--Both water and some organic solvents are ingredients of these decontamination systems. It should be noted that this type of system has been only applied to small-scale decontamination purposes such as skin, cloth, and other small surfaces. Some examples of these systems follow:
 - Fifteen percent (15%) sodium sulfide in a mixture of glycerol, ethanol, and water has been used to destroy HD (7). The total destruction of HD at ambient temperature requires 20 hours (21).
 - Quaternary ammonium hydroxide, sodium hydroxide, or phenoxide in a mixture solution of dimethyl sulfoxide and water or alcohol has been reported to be an effective skin decontaminant for HD (7). However, its effectiveness against G and V was not mentioned.

- A mixture of 70% methyl cellosolve and 30% of a 50% aqueous sodium hydroxide solution gave complete destruction of HD in 2 hours (7). This mixture has a relatively large capacity for HD decontamination and is more favorable than other H decontaminants (7).

- Two emulsion formulae, Turkey red oil (5%), 95% ethanol (35%), and sodium hydroxide (2.5%) in water; magnesium oleate (2.5%), lubricating oil (20%), and calcium carbonate (3%) in water have been used for H decontamination (18). The rate of emulsion for H was reported to be rapid, but the rate of hydrolysis was slow. Currently, an all-purpose emulsifying decontaminant has been developed by unidentified foreign powers for vehicle and equipment decontamination (21). This emulsion consists of 8% calcium hypochlorite, 15% perchloroethylene, 1% emulsifier (unspecified mixture of alkylbenzene sulfonate and polyglycol ether), and 76% water. Field tests indicated that this formula was capable of H and G decontamination but was ineffective for V.

- Nonaqueous solutions--The main advantage of nonaqueous decontaminant systems is that the agent is usually more soluble in organic solvents, hence, promotes a more homogeneous contact of agent and decontaminant molecules; intimate contact of the two reactants increases the chemical reaction rate. In some cases, however, the dielectric constants of the organic solvents are lower than that of water, and may actually slow the reaction. The following statements detail the nonaqueous decontaminants identified in the literature:
 - DS-2 as an all-purpose and yet effective decontaminant has been cited by numerous reports (7). It is a relatively corrosive superbase which consists of 70% diethylenetriamine, 28% 2-methoxy ethanol, and 2% sodium hydroxide. The half lives for HD, GB, and VX in DS-2 at room temperature

were found to be less than 3 seconds, 30 seconds, and 7 seconds, respectively (7). Although an attempt was made to improve DS-2's decontamination effectiveness (i.e., faster, less corrosive, etc.) by modifying the formulation, none of the substitute formulations were found to be markedly superior to DS-2 (7, 36). It was reported (12) that the decontamination ability of DS-2 sprayed on clothing coupons is far better than either 10% peracetic acid, 10% monochloroperoxyacetic acid, hypochlorite acid (0.15M), uranyl nitrate (0.1M), or thorium nitrate (0.1M). During an attempt to determine the effectiveness of DS-2 as a mist for the decontamination of agents on the M17 and XM29 mask components, it was found that DS-2 did not cause a change in the agent (H, G, V) permeation rate for butyl rubber up to 1000 minutes even though DS-2 contains a solvent fraction. Also, results indicated that DS-2 did not cause any operational problem associated with the filter (5).

- Air Force CD-1 (also known as APD) is also an all purpose decontaminant. It consists of 55% (V/V) of monoethanolamine, 45% (V/V) of 2-hydroxyl-1-propylamine, 25% (Wt/V) of lithium hydroxide monohydrate. When VX is in APD (1% of VX by weight), up to 99% of VX disappeared in 15 minutes. For GB, up to 99% of agent was destroyed in 2 minutes. When compared to DS-2 under the same laboratory conditions, CD-1 is less desirable for decontamination not only because CD-1 destroys HD slower than DS-2 but also because the end product of the APD and HD mixture is still quite toxic (7, 37).
- Sodium hydroxide in methanol or ethanol has been experimentally studied for decontaminating V. The results are not promising because of the slow hydrolysis rate (i.e., half life is approximately 11 hours) (7). Sodium hydroxide in dimethyl sulfoxide (DMSO) as a superbase has been suggested for decontaminating HD, but no tests have been

conducted (7). However, DMSO is an excellent solvent and possibly could carry unreacted agent through the protective garment to the skin.

- Benzyltrimethylammonium hydroxide in methanol has been studied by the Navy as a potential decontaminant. No detailed data have been released (7).
- Monoethanolamine (MEA), an organic solvent which in itself is a relatively strong base, has been used for decontaminating HD. The half life of HD is 32 minutes at 25° C when the ratio of agent to decontaminant is 2 to 1 (V/V) (7). MEA combined with 4-(N,N-dimethylamine) pyridine has been used for GB decontamination (7, 28); results indicated that GB was almost completely destroyed on contact. Similar types of strong-base bulk reagents which are available in storable formulations are lithium hydroxide in MEA and sodium hydroxide and diethylenetriamine in methyl cellosolve (28). However, their effectiveness against V was not reported.
- Alpha nucleophiles, even though less basic than the above-mentioned bases, will attack and react with agent more rapidly than hydroxide ions. This is because alpha nucleophiles present an unshared electron pair on the atom next to the one bearing the negative charge. Hydroperoxide, oximes, and hydroxamic acid compounds are examples of alpha nucleophilic reagents. A number of theoretically promising alpha nucleophiles have been synthesized such as oximinovaleronitrile, ethylenediaminetetraaceto-hydroxamic acid, amylose oxime, and fluorobenzaldoxime. However, these compounds decontamination capability is yet to be determined.
- Pyrocatechol and pyrogallol anions are bidentate nucleophiles and were found to hydrolyze organophosphate rapidly.

Here too, agent decontaminating capability is yet to be experimentally determined (28). Oximes with a large aliphatic moiety should enhance organophosphate hydrolysis rates [e.g., the half life of VX in a pH 9.3 solution containing dodecylpyridinium-3-aldoxime iodide (10^{-3} M) is 40 seconds] (7); no decontamination experiment has been conducted.

-- Macrocyclic ether-alkali metal salts, organic complexes, have been examined for their decontamination capability toward agents at or near room temperature in non-aqueous solvents (38). Among five of the macrocyclic ethers investigated, cryptand (2,2,2) and 18-crown-6 were most effective in facilitating agent destruction. In absolute ethanol, with a 1:1 equivalent concentration ratio of crown ether and agent, the crown salt with potassium hydroxide complex destroyed 98, 99, and 100% of HD, VX, and cyclohexyl methylphosphonofluoridate (GF) (a GB analog), respectively, in 5 minutes (38). Because alkali metal hydroxides are too corrosive for use on skin, a salt of this reagent, the potassium acetate-crown complex in benzene has been tested for its decontamination capability against agents. The results showed that 54% of GF, 82% of VX, and 99% of HD can be destroyed within 2 minutes (38). Although the preliminary study on agent decontamination by macrocyclic ether-alkali metal salt complexes are quite promising, relatively high toxicity of one of its members has limited its' decontamination application (39). In addition, because these macrocyclic compounds are not generally available from commercial sources, the need for synthesizing them in quantity will further hamper their potential applications for this project. However, market demand can readily reverse this situation.

-- Several other novel organic molecules reported in the literature would require syntheses that are beyond the scope of this project. Examples of these compounds are

bromodimethyloxazolidone, dimethylaminopyridine, poly-ethylenimine, and imidazole (28). Unfortunately, their detoxification capabilities toward agents are not known; no evaluation data have been given in the literature.

7. CURRENT STANDARD DECONTAMINANTS USED IN THE U.S. ARMY

Before evaluating any new or relatively new potential agent decontaminants, the current status of standard decontaminants used by the U.S. Army will be discussed. The U.S. Army presently uses both physical and chemical approaches to decontaminate chemical warfare agents (24). These two standard approaches are outlined below.

7.1 Physical Procedures.

Physical procedures do not detoxify chemical agents, but only remove the agent from contaminated personnel, equipment, and/or terrain. One of the most important large-scale physical removal methods is aeration, either natural or forced, resulting in agent dispersal into the air. Natural weathering, which includes forces other than air alone, (e.g., temperature, ultra-violet light) is probably the most important decontamination procedure available where time limitations are not a factor. Natural weathering, in most cases, will not be applicable to decontaminating casualties. Once the time lapse prior to treatment must of necessity be short if exacerbation of injuries is to be avoided.

Active physical removal approach includes the use of flat stick pads containing Fuller's Earth (such as in the ABC-M13 Kit), heat in the form of fire or steam, and high pressure water rinses. Another method is simple washing with hot soapy water. Again, these approaches will not suffice for processing casualties.

7.2 Chemical Procedures.

There are two general categories of chemical decontaminants presently in use to detoxify chemical agents, standard and field expedient decontaminants. Standard decontaminants are those developed specifically for use by

military personnel, and field expedient decontaminants are those chemicals that are readily available for use in a military environment.

The standard decontaminants are DS-2, supertropical bleach (STB), and the components of the ABC-M13 and M258/M258A1 decontamination kits. Table 2 lists the U.S. Army standard chemical decontaminants and the corresponding agents they are effective against.

TABLE 2. U.S. ARMY STANDARD CHEMICAL DECONTAMINANTS

<u>Decontaminant</u>	<u>Agents Detoxified</u>
STB	Blister and Nerve Agents
DS-2	All Agents
ABC - M13 Kit	Blister and V- Series Nerve Agents
M-258 Kit/M258A1 Kit	All Agents

STB may be mixed with water to form a wet slurry or it may be mixed with dry earth, sand, or ashes to form a dry mix. The dry mix of STB has been used by the Army in shuffle boxes to decontaminate boots (16).

DS-2 is a clear solution that is applied with the M11 apparatus to contaminated areas.

The ABC-M13 individual decontaminating and reimpregnating kit is designed to be used by individuals to decontaminate droplets of all chemical agents on skin or clothing. This kit consists of a pad containing Fuller's Earth powder for use in absorbing liquid agents plus two cloth bags of chloramide powder (XXCC3) for detoxification purposes.

The M258 skin decontaminating kit consists of two capsules containing decontamination solutions, two flat wooden scraping sticks, and four gauze pads, in a plastic container. One of the gauze pads is used to soak up as much liquid agent from the contaminated skin as possible. If the contaminant is a thick liquid, it is first scraped off with the scraping sticks. A second gauze pad wetted with solution 1 is then rubbed over the contaminated area.

Subsequently, the third pad is used to apply decontamination solution 2. Solution 1 consists of sodium hydroxide, ethanol, and phenol, and is used to detoxify G; solution 2 contains chloramine-B and zinc chloride in a water-ethanol solution, and is used to decontaminate H and V. A modification of the M258 Kit, the M258A1 Kit, has presoaked the decontaminating towelette sets which are then used in a similar manner as the gauze pads.

A large number of field expedient decontaminants have been identified by the Army for the detoxification of chemical agents. Among these are ammonia (NH_3), caustic soda (NaOH), sodium carbonate (Na_2CO_3), lime (CaO), laundry bleach (5% NaOCl), and trisodium phosphate (Na_3PO_4). Oxidation by fire and steam hydrolysis are other field expedient techniques. These decontaminants and techniques, however, are generally not effective against all agents and cannot be used for obvious reasons on casualties.

8. INDUSTRY SURVEY FOR AGENT DECONTAMINATION

Numerous telephone inquiries and personal interviews with private industries were conducted to search for new decontamination agents and techniques. However, only a modest amount of information, which may be useful for agent decontamination, was obtained during this survey. The results of this investigation are summarized below. Organizations contacted during this survey are listed in Appendix B.

8.1 Rohm and Hass Company (Spring House, Pennsylvania).

Three new types of high surface area polymeric resins have been developed for application in agent decontamination. These three types of resins are carbonaceous adsorbents, polymeric adsorbents, and reactive resins. Each type of adsorbent is briefly described below, although specific compositions, being proprietary, have not been revealed.

- Carbonaceous adsorbent--These adsorbents have been found to have higher gas phase dynamic capacities for simulants and agents (HD, GD and cyanogen chloride) than granular activated carbon. The dynamic capacity of these adsorbents is not reduced when the

relative humidity is increased, even to 100%. Carbonaceous adsorbent activity can be regenerated under mild conditions, such as being purged with low pressure steam, hot air, or an organic solvent. Under normal operating conditions, these resins reportedly retain the agents more tenaciously than granular activated carbon. The individual resin beads are very strong and are resistant to attrition. Specific data have not been released.

- Polymeric adsorbents--These adsorbents have been tested by Rohm and Hass and found to have high capacities for simulants, such as diisopropyl fluorophosphate and dimethyl methyl phosphonate; capacities are well over twice that of granular activated carbon. Tests of these materials with agents have not been done to date. These polymeric adsorbents function well at high humidity and can be regenerated under mild conditions according to the company.
- Reactive resins--These resins are highly functionalized forms of the polymeric adsorbents. They combine the high capacity of the polymeric adsorbents with a wide range of active chemical groups. These chemical groups include all of the groups normally used in ion exchange resins and many groups which are prepared specifically for chemical defense applications. Both catalytic and stoichiometric reactions involving attached functional groups have been demonstrated. Rates of reaction of functional groups attached to polymeric resins can exceed the rates of reaction of those groups attached to small molecules. Many of the reactive resins investigated can be easily regenerated. Reactive groups on polymers are far less corrosive than the same free functional groups toward such substrates as metal, paint, and skin. Again, data are not publicly available.

Comment: Reactive resins, which act as adsorbents, detoxicants, and coatings could be very promising decontaminants for the MCCA-M project if company claims are correct.

8.2 H. B. Fuller Company (St. Paul, Minnesota).

Three types of chemical materials, which could act as fast-setting polymers to seal agents onto clothing, were recommended. Each type of chemical is briefly described below:

- Low molecular weight wax--This material can be applied to contaminated surfaces by spraying. Application temperature will be around 125° F, and spray pressure will be 30 psi (pounds per square inch). Wax setting time is estimated to be less than 2 minutes.
- Water based adhesive polyvinylacetate--This polymer can be sprayed onto contaminated surfaces, but the setting time is estimated to be longer than 10 minutes hence, of doubtful use in handling casualties.
- Urethane powders (Product numbers VR2151 and VR2194)--These are required to be pre-mixed before application. The setting time is estimated to range from 30 seconds to 8 minutes, depending on actual chemical formulation.

Comment: Low molecular weight waxes, which are nontoxic and inexpensive, could be a feasible approach to sealing off agent-contaminated clothing.

8.3 Chemical Coating and Engineering Corporation (Media, Pennsylvania).

Hypalon--This is a trade name for an elastomeric material that can be sprayed after mixing with an organic solvent, such as acetone or hexane; it can set within 2 minutes.

Comment: Organic solvents may enhance the penetration of agents into the inner clothing materials. This product cannot be recommended for use as a decontaminant at this time.

8.4 3M Company (St. Paul, Minnesota).

Spray adhesive (3M-77)--This adhesive has been formulated into aerosol form.

Comment: A very small amount of 3M-77 spray adhesive can be sprayed onto contaminated surfaces followed by dusting with a containment powder. Results of this application may be similar to those obtained from use of fast-setting polymers which act as sealants for agents.

8.5 Lab Safety Supply Company (Janesville, Wisconsin).

Sticky mat--These are paper-type sheets with sticky surfaces that can be used to wrap around contaminated casualties still in MOPP-level 4 gear to serve as a sealant against agents.

Comment: Preliminary tests indicate that the existing sticky mat requires modification and improvement in order to satisfy this project's requirements. The product currently available did not adhere to standard protective garb. However, the concept of using sticky mat for wrapping around contaminated casualties is a novel one.

9. EVALUATION AND ANALYSIS

Theoretically any decontaminant which does not meet the criteria delineated in this document's introduction shall be excluded from further analysis. However, CSC-EL personnel believe that a systematic screening for potential decontaminants is feasible. Based on the information outlined in the Section 6. and 8. (i.e., Literature Review and Industry Survey for Agent Decontamination), the top three or four potentially most efficient decontaminants in each feasibility category were selected and listed in table 3 for comparison and trade-off analyses. The data for each decontaminant in table 3 were obtained either from the literature or from telephone inquiries. Data sources are listed in table 3 for reference purposes.

TABLE 3. THE MOST EFFECTIVE DECONTAMINANTS IN EACH FEASIBILITY CATEGORY

Decontaminant	Corrosiveness	Storage Stability	Safety	Agent		Rate of Action	Logistic Burden ^a (Chemical agent)	Reference Source	Remarks
				Specificity	Destruction				
<u>SOLIDS:</u>									
Activated charcoal	No	High	Non-toxic	All	No	~90% ^b	2 mg/cm ²	12, 21	Use on filters and clothing
Fuller's Earth	No	High	Non-toxic	All	No	~90% ^c	5:1	7, 14	NATO's decontaminant
Silica gel	No	High	Non-toxic	All	No	N/A	N/A	14	Used in Warsaw Pact JPM kit
<u>CONTAMINANTS:</u>									
Cerncol	No	High	Non-toxic	All	No	Minutes	N/A	21	Strong absorbent
Starch	No	High	Non-toxic	All	No	Minutes	N/A	21	Weak absorbent
Fast-setting polymer	N/A	N/A	N/A	All	No	Minutes	N/A	N/A	Not commercially available
<u>WATER/ORGANIC SOLVENTS:</u>									
Detergent Water	No	High	Yes	All	No	Slow	Bulk	22	Vehicle decontamination
JP-4	No	High	Flammable	All	No	Slow	Bulk	22	Vehicle decontamination
Alcohol	No	High	Flammable	All	No	Slow	Bulk	22	Used often as a solvent for skin decontaminant
<u>OXIDATIVE CHEMICALS</u>									
Hypochlorite salts	High	Low	Toxic vapor	H, V	Yes	Minutes	~5:1	7, 13	US Army standard decontaminant
Chloroxine B and T	Medium	Medium	Less toxic	H, V	Yes	Minutes	~10:1	25, 29	Component of M250 or T58A1 kit
EXCC (Dichloroxine group)	Medium	Medium	Less toxic	H, V	Yes	Minutes	~10:1	7	Component of ABC-M13 kit, protection clothing
<u>HYDROLYTIC CHEMICALS</u>									
Cu (III)-TMEDA	Medium	Medium	Less toxic	All	Yes	Minutes	~3:1	33	Promising test data
DS-2	Medium	Medium	Toxic	All	Yes	~95% in minutes	~2:1	7	US Army standard decontaminant
Cryoland-sodium hydroxide	Medium	High	Toxic	All	Yes	Minutes	~2:1	21	Promising test data
Cryoland-sodium acetate	Low	High	Less toxic	All	Yes	Minutes	~2:1	30	Promising test data
<u>INDUSTRY SURVEY</u>									
Reactive resin	No	High	Min. Toxic	All	Yes	Minutes	N/A	Baker and Hess	New product, (no test data)
Low molecular weight wax	No	High	Non-toxic	All	No	Minutes	~2:1	M. B. Fuller	No test data
3M-77-spray adhesive	No	High	Min. Toxic	All	No	Minutes	~2:1	3M	No test data
Sticky Mat	No	High	Non-toxic	All	No	INSTANT	N/A	Lab safety supply	Product requires modification

^aThese figures are approximate estimates based on literature and industry sources.^bFrom skin in two minutes.^cFrom cloth in two minutes.

9.1 Sorbents.

Fuller's Earth is a very promising non-selective decontaminant which physically absorbs the agent and has long been used by NATO for decontamination purposes. Activated charcoal and silica gel dust are second choices. However, the disadvantage of sorbents is that they will not destroy the agents which will eventually off-gas to again contaminate the environment. This may constitute an acceptable risk if the sorbent is removed in a timely manner from the environment of concern. However, the physical nature of this material may not only preclude ready removal, but may result in its distribution into other areas of the shelter. Nevertheless, it may be desirable to have sorbents available for standby measures.

9.2 Containment Materials.

Containment materials (such as starch or ground corncobs) with adhesive chemicals or fast-setting polymers that bond to both agents and clothing, provide blocking and sealing effects. Although this approach does not actually detoxify agents, it will generally fulfill the stated requirements of this task, because it will protect both wounded personnel and medical staff from agent exposure in any form. It should again be emphasized at this point that our concept of the function of the MCCA-M is to safely remove casualties from contaminated gear without endangering attendant personnel rather than the former concept of achieving complete decontamination. Although subtle, the difference in concepts is important.

A fast-setting polymer (such as to a latex system) providing excellent sprayability, film formation, and flexibility, is strongly favored for this project. However, a fast-setting latex system is currently not available in the commercial market and is yet to be developed. An alternative involving sequential application of a 3M spray adhesive and then starch or corncob powder may also meet the decontamination criteria. Reactive resins (Rohm and Hass) and low molecular weight waxes (H. B. Fuller) are also to be actively considered based on current available data and theoretical projections.

9.3 Water/Organic Solvent.

Detergent-water, alcohol, and JP-4 are the most commonly mentioned solvent systems for agent decontamination. However, these solvents cannot be considered for decontamination of casualties due to obviously unsafe and inefficient actions.

9.4 Oxidative Chemicals.

Among the oxidative decontaminants, ASH, SPLASH, HTH, STB, chlorinated lime, and Solution I are apparently effective detoxicants. However, because they present a toxic vapor hazard, are corrosive, difficult to handle, and deteriorate with time even if in the dry state with added stabilizer, they are excluded from consideration in the current project as potential decontaminants.

Although Dutch powder is also a bleach-type decontaminant and presents similar chemical properties to other chemicals (such as HTH and STB), the modified Dutch powder, which has been used by NATO for skin decontamination, will be considered for later comparison analysis.

Hydrogen peroxide is a very good oxidative chemical, but it is too unstable and explosive.

DCICNR, TCTATO, chloramine-B, and chloramine-T are also effective oxidative compounds, but are not recommended as decontaminants for this project because they are water soluble; wetted clothing can result in agent penetration of the protective gear. Dichloramine-B and dichloramine-T are soluble in many organic solvents in which agents are soluble, but they are not stable when exposed to sunlight and moisture. In addition, they do not detoxify G effectively hence, do not meet current requirements. DT-1, DT-2, and DT-6 in dichloroethane are noncorrosive and have been used by Russia to decontaminate agents from skin, clothing, wood, and metal surfaces. However, they are only recommended for H decontamination and do not meet the non-selective criterium. DTS-CK is a general-purpose decontaminant, but it is too corrosive and unstable for storage.

9.5 Hydrolytic Chemicals.

Among the hydrolytic group, DS-2, Cryptand (2,2,2) and its potassium hydroxide complex, and the Cu(II)-TMEDA complex represent potentially the most effective agent decontaminants in each type of classification. However, they are relatively corrosive. Cryptand and potassium acetate in hexane solutions, being less corrosive, can be an alternative decontaminant system if the more corrosive decontaminant such as DS-2 are rejected by USAF.

Theoretically, a corrosive decontaminant (pH above 9) should be eliminated from consideration. However, since only a measured amount (a theoretical maximum of 150 gm/person) of these detoxicants will be applied over the clothing surface and the decontamination process time is very limited, the corrosive nature of these chemicals may become negligible. For this reason DS-2, cryptand-potassium hydroxide, cryptand-potassium acetate, and Cu(II)-TMEDA complex are being considered for the decontamination feasibility tests in the later phase of this project.

After a detoxification reaction, the surface of the protective clothing is likely to be coated by a layer of nondefined less toxic, oily, organic end-product residues. This end-product may be difficult or impractical to remove by chemical solvents or by brushing with abrasive action. Although a complicated surface active solution may be developed for washing out this residue, it may cause a clothing-wetting problem. Therefore, a fast-setting polymeric/containment material coating or sorbent powder is proposed and recommended for application over the chemical residues after the detoxification reaction step in the procedure. The coating will provide a more complete and thorough decontamination effect because it will not only cover the organic residues of any kind but also will prevent agent desorption. Based on the preliminary analyses mentioned above, table 4 lists CSC-EL personnel's recommended potential decontaminants and their commercial availability.

TABLE 4. POTENTIAL DECONTAMINANTS AND THEIR COMMERCIAL AVAILABILITY

Decontamination System No.	Chemical Compositions	Commercial Availability
1.	Fuller's Earth	Yes
	Dutch powder	Yes
2.	Fast-setting polymer	No
	or	
	Starch or corncob with spray adhesive	Yes
	or	
	Low molecular weight wax	Yes
	or	
	Sticky mat	No
3.	DS-2--70% diethylenetriamine	Yes
	--28% glycol monomethyl ether	Yes
	--2% sodium hydroxide	Yes
	Sorbent or containment material	Yes
	or	
	Cu (II)-tetramethylethylenediamine	No
	Sorbent or containment material	Yes
	or	
	Cryptand	Yes
	Potassium hydroxide	Yes
	Hexane	Yes
	Sorbent or containment material	Yes
	or	
	Reactive polymeric resin	Yes
	Sorbent or containment material	Yes
4.	Cryptand	Yes
	Potassium acetate	Yes
	Hexane	Yes
	Hot air	Yes

Based on the results of the commercial availability analysis as listed in table 4, four potentially feasible decontamination systems are recommended for further examination. These systems follow:

- Mix Fuller's Earth powder with Dutch powder at a 1:1 ratio. Apply this mixture evenly over the entire protective gear. Shortly after completion of the chemical reaction, the end-products will be removed by vacuum.
- Apply a fast-setting polymer, low molecular weight wax, or containment material over the entire protective gear. The containment material (such as starch or corncob) can be applied after spray coating the protective gear with adhesive chemicals. An improved sticky mat may be used directly to wrap casualties still in MOPP-level 4 protective gear.
- Apply a detoxicant chemical (e.g., DS-2; copper ligand; macrocyclic ether-alkali metal-salt complex; reactive polymeric resin) over the entire protective gear for agent decontamination. After detoxification, sorbent or containment material will be gently sprayed over the surface of the entire protective gear to produce a protective "cocoon."
- Apply only cryptand and potassium acetate in hexane solution. After detoxification, a flow of hot air will blow dry the protective gear.

From the preliminary analysis, as mentioned earlier in this report, it is believed that only a few chemical formulations can currently qualify as all-purpose decontaminants (preferably true detoxicants) which is one of the key criteria delineated in this report's introduction. These formulae are DS-2, CD-1, DTS-CK, and aqueous bleach. Among them, DS-2 has been generally accepted as the most effective decontaminant for all known agents. Therefore, it is suggested that test data from any decontaminant system be compared to the data that results from DS-2 decontamination under the same test conditions. After the final test data analysis, if DS-2 is still proven to be

superior to the other substances tested for decontamination capability and efficiency, but is rejected by the USAF for safety reasons, the second and third ranked decontamination systems may be recommended for incorporation into the MCCA-M system.

A brief, highly tentative outline for the proposed decontamination methods follows. These methods are for stretcher-type casualties only:

- Gently remove the wounded personnel from the standard stretcher to a sheet of activated charcoal impregnated paper which is laid on top of a specially designed platform.
- Seal the wounded area with a medical patch such as an Abd pad which contains a broad spectrum antibiotic plus an absorbent for chemical agents. The patch is covered with a sterile sheeting (e.g., Op-Site).
- Replace the respiratory filter with a specially designed valve (figure 6).

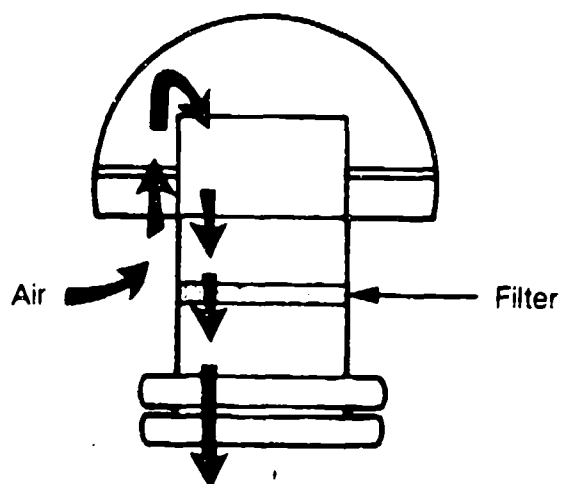


Figure 6. A Specially Designed Valve For Replacement of the Mask Filter

- Wipe the mask eyelens outserts and voicemitter with a cloth soaked with chloramine-B in alcohol (removal of eyelens outserts is an option depending on which decontamination system will be used).
- Cover the cleaned eyelens outserts and voicemitter with sheets of sorbent papers.
- Slide the platform with the casualty into the decontamination room.
- Mechanically apply one of the previously recommended decontaminant systems.
- Slide the platform with the casualty out of the decontamination room.
- Use one or two corpsmen to cut the processed protective clothing from the casualty in accordance with figure 7. Fatigues and undergarments will also be cut away and placed in a separate bag with a patient ID number to recover valuables, etc., when time permits.
- Put the cut protective clothing, along with overboots, gloves, and hood into a charcoal-lined plastic bag. Seal the bag which is then ejected from MCCA.
- Remove the mask and replace with a disposable absorbent-impregnated nose and mouth piece. Place the mask in a plastic bag for ejection to the outside.
- Immediately transfer the casualty to an absorbent material-type stretcher. Specifications for the stretcher will be developed later.
- Cover the naked person with a sheet of adsorptive garment.

- Pass the casualty through an airlock into the medical TFA.

Note: It is again emphasized that the decontamination procedure outlined above is tentative and will be modified as our data base develops.

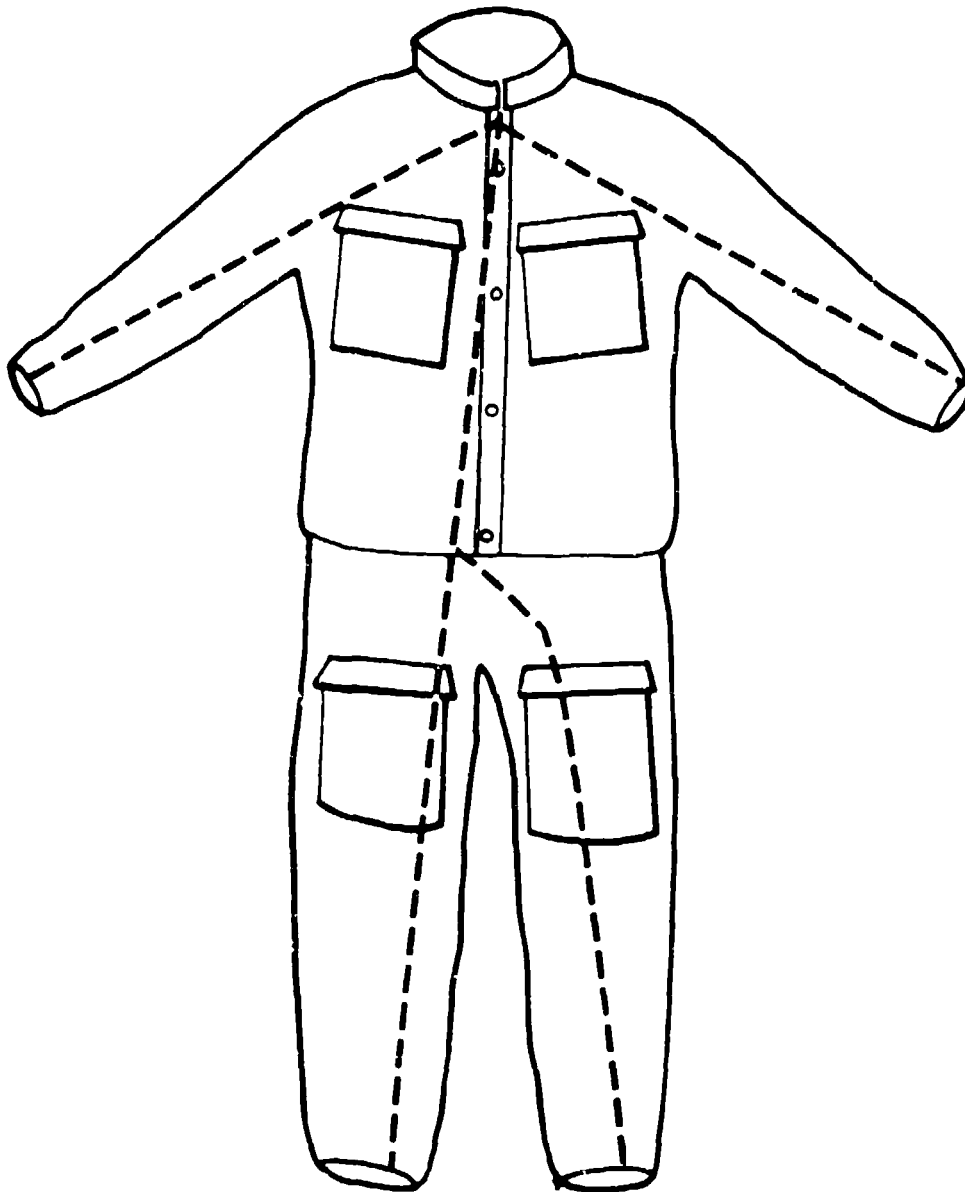


Figure 7. Protective Clothing Cutting Lines.

10. DECONTAMINANT APPLICATION

As indicated in this report's introduction, the decontamination process must be rapid (i.e., completed within 4.0 minutes) and essentially automatic. For safety reasons, the decontaminant formulation must not excessively wet the protective gear and should preferably be toxicologically safe. It is understood that adopted chemicals and processing procedures will not degrade the MCCA integrity. Seven detoxicant/decontaminant application methods have been identified as indicated in the following list:

- Spraying
- Powdering
- Fogging or misting
- Washing
- Foaming
- Containing
- Physically removing (i.e., whipping, swabbing, and rubbing etc.)

The methodology and equipment used for each of the above decontaminating modes will be discussed in more detail following the decontaminant prioritization decision (October 1984).

11. SIMULANTS

Simulants must adequately mimic chemical and physical properties of the agents that are applicable to the test being done. For instance, viscosity, vapor pressure, molecular weight, density, melting point, surface tension, and chemical functional groups are all important parameters for simulant selection. Although the properties of a good simulant should be parallel to the properties of the mimicked agent, in the current project,

chemical functional groups and vapor pressure factors will be given priority. Chemical functional groups will be used to evaluate the detoxification capability of a decontaminant and vapor pressure factors will be used for comparing the decontaminant sealing effect. The simulants considered in this project correspond to the neat form of HD, GD, and VX, respectively. Thickened agents present a special set of problems and will not be addressed in the initial phase of this program.

Table 5 lists the simulants used in previous studies, which are cited in the literature. At the preliminary stage of this study, diisopropyl phosphonofluoridate (DFP) or malathion which has a labile phosphorus-leaving group bound similar to that occurring in GD and VX, and 2-chloroethylmethyl sulfide (CMS) which matches the hydrolytic characteristics of HD, will be selected as simulants for GD, VX, and HD where true detoxification studies are concerned. However, for testing of containment materials or fast-setting polymers, dimethylmethyl phosphonate (DMMP) shall be chosen for its close similarity in volatility to HD and GD.

TABLE 5. AGENTS AND THEIR CORRESPONDING SIMULANTS

<u>Agent</u>	<u>Corresponding Simulant</u>
H	CMS (2-chloroethylmethyl sulfide)
H	TD (2,2 thiodiethanol)
GA	OSP (O-ethyl-S-ethyl methyl phosphate)
GB	DIMP (Diisopropylmethyl phosphonate)
GD	DMMP (Dimethylmethyl phosphonate)
V,G	DFP (diisopropyl phosphonofluoridate)
V	Malathion (diethyl mercaptosuccinate S-ester with o,o-dimethyl phosphorodithioate)
V	TBEP (tris butoxyethyl phosphate)
H,G,V	DEM (diethyl malonate, thickened or neat)

12. CONCLUSION AND RECOMMENDATIONS

Based on the results of an extensive literature search, review, and evaluation, in general, there is no single known decontaminant method that can meet all required decontamination criteria. However, after a careful trade-off analysis, market survey, and deliberation, CSC-EL personnel recommend four potentially feasible decontamination systems for further testing, examination, and comparison. These systems include a combination of two known decontaminant methods; several new industrial products; a family of copper ligands. Following testing, the system showing most promise will be incorporated into the MCCA system for casualty decontamination. The four recommended decontaminant systems are as follows:

- Mix Fuller's Earth powder with Dutch powder at a 1:1 ratio. Apply this mixture evenly over the entire protective gear. Shortly after completion of the chemical reaction, the end products will be removed by vacuum.
- Apply a fast-setting polymer, low molecular weight wax, or containment material over the entire protective gear. The containment material (such as starch or corncob) can be applied after spray coating the protective gear with adhesive chemicals. An improved sticky mat may be used directly to wrap casualties still in MOPP-level 4 protective gear.
- Apply a detoxicant chemical (e.g., DS-2; copper ligand; macrocyclic ether-alkali metal-salt complex; reactive polymeric resin) over the entire protective gear for agent decontamination. After the detoxification reaction, sorbent or containment material will be gently sprayed over the surface of the entire protective gear to produce a protective "cocoon."
- Apply only cryptand and potassium acetate in hexane solution. After detoxification, a flow of hot air will blow dry the protective gear.

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2. Military Specification: Cloth, Twill: Cotton and Nylon. 1974.
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4. Research and Feasibility Studies on Clothing and Decontamination. 1970.
5. Personnel Decontamination Station. 1979.
6. Investigation of Techniques for Decontaminating Personnel Protection Items. 1982.
7. Decontamination Methods for HD, GB, and VX--A Literature Survey. 1981.
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9. Chemical and Biological Warfare: Part I Protection, Decontamination, and Disposal (1964-1978). 1981.
10. Chemical Decontamination of Military Equipment Using Infrared Rays. 1978.
11. Approaches to Decontamination or Disposal of Pesticides: Photodecomposition. 1978.
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13. Sorbent Powder for Chemical Warfare Decontamination. 1982.
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22. Decontamination Field Expedients--Summary of Results. 1980.
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28. Study of Reactive Materials for Development of New Protective Clothing Concepts, A. 1978.
29. Continued Investigation of Surface-Active Displacement Solutions/SADS II Detoxification and Application Data. 1982.
30. Evaluation of Decontamination Formulations. 1981.
31. New Oxidants and Mechanisms of Oxidation. 1967.
32. Decontamination of Surfaces Contaminated with Chemical Agents. 1978.
33. Phase I: A Feasibility Study on the Possible Development of Resin Polymer for the Filtering and Sensing of Chemical Agents. 1979.
34. Study of Agent-Reactive Fabrics for Use in Protective Clothing, A. 1979.
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36. Development of Package Decontaminating System (Final Rept. 29 Jun 71-29 Jun 72). 1972.
37. Studies on the Destruction of Toxic Agents VX and HD by the All-Purpose Decontaminants DS-2 and CD-1. 1975.
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39. Brief Review of the Chemistry of Crown Ethers, A. 1976.

APPENDIX A
REFERENCE SYNOPSES

1. Chemical Defense Design Handbook for Tactical Shelters--Vol. 1.
Chemical and Biological Protection Handbook for Field Personnel.
National Aeronautics and Space Administration--National Space
Technology Laboratories--Engineering Laboratory
AD #: N/A
November 1982

This publication provides guidelines for ensuring safe operations of tactical shelters in a CB environment.

Volume I includes procedures which can be used by personnel to operate tactical shelters more safely in a CB environment. In addition to suggested procedures, this handbook includes guidelines for modifying shelter operations in order to minimize exposure to CB agents and spread of agent contamination. Appendices provide listings and descriptions of chemical defense (CD) equipment used by the USAF, Army, and Navy which is currently in the inventory. In addition, industrial hygiene equipment has been surveyed and several items have been selected for their potential usefulness in shelter operations in a CB environment. Recommendations for suggested use of these items are presented as well as their descriptions.

This handbook is primarily intended to be a ready reference for field use; the detailed descriptions of CB protection equipment, CB agents, and CB defense operations have been modified to provide only the most pertinent data in each of these areas. References have been provided, however, for appropriate technical reports, field manuals, and technical manuals, which contain additional detailed descriptions of these areas.

2. Military Specification: Cloth, Twill: Cotton and Nylon
Author: N/A (MIL-C-43892)
AD #: N/A
1 May 1974

Military specification for protective clothing is detailed in this letter report.

3. Objectives and Systems for Decontaminating in the Field
Robert L. Bryant
AD-515894
28 June 1971

This document presents hazards (CBR) for each class item that might become contaminated (skin, equipment, terrain) and possibilities for reducing these hazards. Advantages and disadvantages, as well as characteristics, of present and forecast candidate systems for decontaminating are discussed and the systems are ranked according to effectiveness. Objectives and systems for decontaminating each item are determined and summarized. Qualitative relationships form the basis for most of the analysis in the study. The scope includes decontamination within the Army field area but excludes the items of food, water, and explosive ordnance.

4. Research and Feasibility Studies on Clothing and Decontamination
G. L. Baude
AD-876647
11 September 1970

Studies on decontamination and percutaneous protection against chemical agents were conducted by the Research Division of Grace and its Dewey & Army Division and under subcontract by Monsanto Research, Molpar, Inc., and the Robinette Research Laboratory. New or improved chemical agent decontaminants were investigated: with selected metals, salts and compounds, phenols, and plasticized ion exchange resins showing the most promise. Attempts to catalytically decontaminate agents by free radical initiated oxidation were not successful. Silicones and silarances were also not effective.

Theoretical and experimental variables were correlated for predicting the performance of fabric impregnants as vapor barriers. The interaction between fabrics or solid sorbent and liquid chemical agents were defined.

5. Personnel Decontamination Station

Arthur K. Stuempfle, Joel Klein, and Bernard V. Gerber

AD-B041888L

September 1979

This document describes procedures for personnel decontamination:

- General procedures for personnel decontamination in a controlled station
- Problems which are required to be improved during the decontamination process
- Several questions and knowledge gaps
- Some decontaminant test data.

6. Investigation of Techniques for Decontaminating Personnel Protection Items

K. J. Williams, J. J. Reidy, G. R. Riley, C. V. Robinson, and D. A. Easter

AD-B073613L

December 1982

As a result of concept discussion sessions and a literature survey, 11 decontamination techniques were selected for testing in this project: conventional oven, infrared, vehicle exhaust, microwave radiation, vacuum furnace, steam wand, steam cabinet, autoclave, ultrasonics, laundering, and boiling. In laboratory tests designed to determine the physical effects of each technique on various personnel protection items, samples of each item were subjected to each decontamination technique. The samples were then

inspected for fading, staining, discoloration, and shrinkage, followed by testing on a tensile-testing machine to determine the extent of tensile strength loss caused by the particular technique.

Using the estimated damage criteria, the following results were obtained: conventional oven--all items but Nomex degraded; infrared--all items but Nomex degraded; vehicle exhaust--all items but Nomex discolored or lost tensile strength; microwave radiation--caused charring or melting of canvas, gloves, webbing, boots, and overgarment foam; vacuum furnace--caused discoloration of a number of items and caused a large loss in tensile strength of the gloves, boots, and winter jacket liner; steam wand--caused least damage of any technique; steam cabinet--stained butyl cloth, discolored webbing, faded summer combat and canvas, shrank canvas, and caused a loss in tensile strength in canvas and winter combat uniform liner; autoclave--faded cotton fatigues and canvas, discolored butyl cloth and webbing, shrank overgarment foam and webbing, and form liner; ultrasonics--faded butyl cloth, discolored Nomex and canvas, shrank webbing, caused a loss of tensile strength in winter combat uniform and butyl cloth; laundering--faded most fabrics, shrank canvas, discolored overgarment foam and butyl cloth, caused stickiness in gloves, shrank canvas, and caused a loss in tensile strength in the fatigues, canvas, and winter combat uniform liner; boiling--faded the overgarment foam and webbing, discolored the butyl cloth and the outer shell of the winter combat jacket, shrank webbing and canvas, and caused a loss in tensile strength for the canvas and fatigues.

7. Decontamination Methods for HD, GB, and VX--A literature Survey
Harvey W. Yurow
AD-B057349L
April 1981

A literature survey was made, covering the period 1978-1981, for all methods reported for the decontamination of the chemical warfare agents HD, GB, and VX. Classes of chemical decontaminants described include strong bases, complexing agents, nucleophiles and oxidants. Physical methods cited were thermal and photochemical degradation and physical collection.

8. Chemical and Biological Warfare: Part II Protection, Decontamination, and Disposal. 1978-1982 (Citations from the NTIS Data Base).

AD #: N/A

May 1982

Government sponsored research is cited in the following four areas: agent disposal by incineration, injection wells, ocean dumping, and chemical deactivation; decontamination and removal of agents on equipment, on clothing, in water, and from air including filtration and adsorption; collective protection systems for buildings, shelters, and vehicles; and protective clothing. (This updated bibliography contains 101 citations, 47 of which are new entries to the previous edition.)

9. Chemical and Biological Warfare: Part I Protection, Decontamination, and Disposal. 1964-1978 (Citations from the NTIS Data Base).

AD #: N/A

January 1981

This bibliography contains citations in the following four areas: agent disposal by incineration, injection wells, ocean dumping, and chemical deactivation; decontamination and removal of agents on equipment, on clothing, in water, and from air including filtration and adsorption; collective protection systems for buildings, shelters, and vehicles, and protective clothing. (This updated bibliography contains 256 citations, none of which are new entries to the previous edition.)

10. Chemical Decontamination of Military Equipment Using Infrared Rays
Captain Mikho Penkov

AD-B026239

17 April 1978

The feasibility of using infrared rays for agent decontamination of military equipment is discussed.

Infrared radiation is a stream of electromagnetic radiation, which results from the oscillatory and rotary motion of the atoms and molecule of matter at a temperature above absolute zero. The infrared spectrum occupies the region of radiation having a wavelength from 0.8 to 1000 μm , i.e., from the red boundary of visible light to the shortwave portion of the millimeter band. Therefore, infrared radiation has the properties of both visible light and radio-frequency radiation, i.e., it changes direction during reflection and refraction like visible light. At the same time, like radio waves, infrared rays can pass through some materials that are opaque to visible light. The thermal effect of infrared radiation can be used for simultaneous heating of all layers to create better conditions for vaporization of the toxic chemical agents.

The infrared decontamination method provides for high productivity, eliminates manual labor, achieves more complete decontamination of all toxic chemical agents, does not damage paint, and does not cause rusting, which in turn eliminates the necessity for additional treatment of decontaminated objects. The method uses a cheap, domestically produced, and readily accessible fuel.

It is apparent from all that has been said, that decontamination by means of infrared rays is a promising method, and it deserves more thorough investigation and implementation.

11. Approaches to Decontamination or Disposal of Pesticides:

Photodecomposition

Jack R. Plimmer

AD #: N/A

1978

Photochemical destruction of organic pesticides has not achieved the status of a technological process that is applicable on a large scale; indeed, its potential for detoxication of wastes or rendering them more susceptible to microbial degradation has been little explored. There is an important need to develop more data on rates and efficiencies of photochemical reactions. Without this basic data, there is little point in discussing the question of

installation design and calculation of operating costs. In this discussion, some limiting factors and indicated areas where progress is desirable are outlined below:

- How rapidly do photochemical reactions occur, and what are their energy requirements?
- How can some of the limitations be overcome?
- What products are formed in photochemical reactions of pesticides?
- What is the cost?

12. Methods and Material for Personnel and Equipment Decontamination; Final Report for Task No. 24 on Collective Protection Against CB Agents; Book I--Unclassified Data. 1970.

R. A. Sturgill and R. M. Sanders

AD-883442

November 1970

Full scale CB pod entry studies were made with manikins in sateen, liner, and carbon overgarment outfits. Manikins were challenged with (1) dimethyl hydrogen phosphite levels of 100, 500, and 1000 mg-min per m³ and (2) diisopropyl hydrogen phosphite droplet level of 3000 mg per manikin. Challenge level, pre-entry aeration time, and decontamination procedures were evaluated for each outfit and for each contaminant level. Full-scale, simulated 8 agent shelter entries, were made. Test personnel were challenged at 10³ and 10⁴ Sm per cu ft. Conditions were evaluated for personnel challenge and pod-and-personnel challenge. The effect of peracetic acid on biological simulants Sm and Bg and chemical agents GB and VX was investigated. Hypochlorous acid, chloroperacetic acid, thorium nitrate, and uranyl nitrate were used on GB and VX and compared to DS-2 for effectiveness.

13. Sorbent Powders for Chemical Warfare Decontamination
Thomas B. Stanford
AD #: N/A
April 1982

A type of Fuller's Earth (Surrey Finest) mined in Great Britain has proven to be effective for the adsorption of CB agents. The objective of this study was to identify domestically available sorbent powder substitutes for Surrey Finest which are equally capable of CW agent absorption. In tests conducted with 22 Fuller's Earth materials against liquid- and vapor-phase CB agents, it was found that 20 Fuller's Earth materials exhibit better sorption properties than Surrey Finest.

14. Survey of New Sorbents for Application to Protection Devices
Leonard A. Jonas and Jaqueline M. Eskow
AD-A022 354
March 1976

The purpose of the study was to update and bring to the forefront a survey of sorbents for application to monitoring and detecting devices. Because of an ever-increasing need for protection against contaminated airstreams, the United States and the United Kingdom are conducting a literature search to correlate past and present developments in the adsorbent field. Sorption is a basic requirement for respiratory protection, protective clothing, collective protection decontamination and detection, and monitoring of unpurified air. This collaborative research would lead to effective and simpler forms of chemical protection. Since gas adsorption remains the basic mechanism by which protection against chemical agents is obtained for both collective and individual items, a periodic survey of new sorbents is important. It has been found that: (1) A large number of carbons are commercially available which have internal surface areas that are greater than that of the standard Pittsburgh carbon. These carbons could be used to provide significantly increased protection against physically adsorbed chemical agents. (2) A large number of macroreticular resins, ion-exchange resins, and catalysts have properties which can cause chemical changes in agent vapors producing nontoxic

products. Consideration should be given to the proper use of such resins and/or catalysts which, in combination with carbonaceous sorbents, could provide optimal mixtures for overall protection against toxic agents.

15. Compounding Techniques for Absorbent Decontaminants

Dewey P. Parks

AD-893611

January 1972

The objective of the program was to develop decontaminating systems for persistent chemical agents using micronized carbon. These systems must be effective in absorbing chemical agents and designed to the following goals: act rapidly over a wide temperature range; be non-toxic and remain stable; not damage material and equipment on contact; and be easily and rapidly applied to vehicular equipment, clothing, and ancillary equipment.

The method of study was to select key ingredients, i.e., activated carbons, thixotropic agents, dispersants, pigments and solvent/antifreeze, and formulate a system containing a minimum of 25% active carbon. It should be easily applied by spraying to a coverage of 4 mg/cm^2 and remain stable (not settle during static storage of at least two years). Key methods of investigation included evaluation of mixing techniques; effects of various thixotropes and dispersant on viscosities and stability; and the evaluation of spray equipment for optimization of techniques as well as equipment. In addition, studies were conducted whereby dry formulation of the same key ingredients were formulated. These compounds were tested for uniformity, adhesion to woven surfaces and effect coverages in the 4 mg/cm^2 range.

The results of these studies show that formulations containing approximately 35% active carbon can be easily sprayed to the desired coverage and will remain stable for the desired two year period. All of the program goals outlined above were met or exceeded by this study. Results also show that dry formulations can be prepared by a special screened milling process to give the desired uniformity, color, and adhesion.

It is concluded that in selecting the optimum ingredients to prepare a stable, sprayable thixotrope that will meet all of the Edgewood requirements, the following materials have shown to be superior: coal, petroleum, coconut and wood based activated carbons are suitable as agent absorbents, however, the coal and petroleum-based appear slightly superior. Dispersants are effective in lowering viscosities with the sodium salts of polymerized substituted benzoid alkyl sulfonic acid being most effective. Color can be obtained with iron oxide and one-half percent sodium chromate or sodium silicate to inhibit rust. A homogenizer will produce uniform mixtures of the wet-system and a special screen milling machine will prepare satisfactory dry formulations.

16. Chemical, Biological, and Radiological Decontamination.
Department of the US Army Technical Manual
AD #: N/A
November 1967

The chapter 2 of this document is concerned with chemical decontamination and consists of three sections. Section I is an introduction and general discussion of chemical decontamination. Section II is a discussion of the decontaminants which may be used for decontamination of chemical agents, and Section III describes the recommended method for decontaminating various surfaces.

17. Proceedings of the International Symposium on Protection Against Chemical Warfare Agents Held at Stockholm, Sweden on June 6-9, 1983
National Defense Research Institute ABC Research Department
AD #: N/A
June 1983

The report contains the Proceedings from The International Symposium of Protection Against Chemical Warfare Agents, which took place in Stockholm 6-9 June, 1983. The papers were presented during sessions entitled Detection, Medical Protection, Respiratory Protection, Decontamination, Civil Defense, and Collective Protection, and Miscellaneous.

For technical reasons, the deadline for submittance of manuscripts had to be changed at a very late stage, and, therefore, only abstracts are available of some papers. However, a supplement containing the remaining full papers was published during autumn, of 1983.

18. History of Research and Development of the Chemical Warfare Service through 1945: Decontamination of Chemical Agents. Part I
J. Mankowich, A. F. Butcosk, R. Robbins, W. B. Roberts, A. L. West, and S. Love
AD-872030
June 1970

Decontamination as described in this monograph is limited almost completely to methods and apparatus for the amelioration of personnel, terrain, structures, clothing, equipment, vehicles, and vessels contaminated with mustard [H:bis-(2-chloroethyl) sulfide]. In order of presentation and length, there is to be found a survey of historical decontamination procedures, a discussion of demustardization methods for the period from 1920 to the early 1940's, and a description of the evolution of apparatus for the implementation of these methods. The military characteristics of 41 devices and two systems evolved in the study of methods and materials for decontamination are presented. Detailed consideration is given to the technical aspects of chemical agent decontamination. Such factors include the nature of the reactions between contaminants and decontaminants, the mechanism of detection reactions, and the analyses, physical and chemical properties, and stability of the divers decontaminants. A history of the development and design for each of the major systems; pieces of apparatus and techniques; the interrelation between them; and their individual, sequential, and concerned application has been prepared and included.

19. Detoxification of Pesticides Using Soluble or Immobilized Enzymes
D. M. Munnecke
AD #: N/A
1978

Systems employing microbial enzymes which have the capacity to degrade toxic pesticides may constitute new technology for detoxification and disposal of pesticides. This paper reviews certain aspects of enzymatic degradation of pesticides and discusses research concerning the utilization of cell-free or immobilized enzymes in engineered systems for the industrial scale detoxification of pesticides in waste waters, pesticide containers, or spray tank rinse waters. A subject of environmental laws, methods of pesticide disposal, microbial pesticide metabolism, cell-free enzymatic pesticide degradation, and industrial enzyme application have been briefly discussed.

20. Engineering and Development Support of General Decon Technology for the U.S. Army's Installation Restoration Program Task 5. Facility Decontamination
William E. Jones, Janet Mahannah, Suzette Sommerer, and Judith F. Kitchens
AD-A117565
July 1982

This report presents a technical evaluation of current and potentially useful methods for decontaminating facilities contaminated with explosives and chemical warfare agents. Several alternative methods were identified as applicable to the problems depending on the contaminant and medium contaminated.

21. Survey of Decontamination Methods Related to Field Decontamination of Vehicles and Materiel (Abridged)
Frank Block and George T. Davis
AD-B031659
October 1978

Basic and applied work on chemical agent decontamination are reviewed, particularly regarding field decontamination problems. Application of some foreign systems are discussed. Suggestions of promising avenues for improvement are provided in the conclusions.

22. Decontamination Field Expedients--Summary of Results

Author: N/A

AD-C021098

February 1980

Contamination levels of thickened agents can be effectively reduced on non-porous surfaces within an operationally realistic time with the use of field expedient materials (3 to 11 percent of the agent challenge remaining following decontamination).

The order of effectiveness for field expedient decontaminants against thickened GD (TGD) on bare and alkyd-painted metals was JP-4 > diesel > 50/50 aqueous ethylene glycol > Dugway Proving Ground clay soil.

The order of effectiveness for field expedient decontaminants against thickened HD (THD) on bare and alkyd-painted metals was JP-4 > diesel > DPG clay soil > 50/50 aqueous ethylene glycol.

Field expedient decontamination and/or weathering may be required in addition to a cover for reducing contamination levels below the lowest reported threshold dose referenced in this report for TGD

23. Military Chemistry and Chemical Agents

Department of the Army and the Air Force

AD #: (TM 3-215 or AFM355-7)

August 1956

Chapter 7 of this document discusses all types of decontaminants with emphasis on their chemical reactions. The chemical reactions include oxidation, chlorination, reduction, and hydrolysis. Chemicals used as decontaminants may be either inorganic or organic compounds which contain chlorine readily available for use as an oxidizing or chlorinating agent. Inorganic compounds include bleach in various forms, calcium hypochlorite, and chlorine itself. They decontaminate by oxidation and are used for large scale decontamination. Organic compounds include the chloramides and closely related compounds. They

decontaminate, in absence of moisture by chlorination, in presence of moisture by oxidation. These compounds are usually dissolved in an organic solvent such as carbon tetrachloride or acetylene tetrachloride; they are expensive, however, and are used only for small scale operations such as for destroying blister gas on equipment.

24. Toxic Substance Control: Decontamination Symposium
George G. Outterson and Theodore M. Prociv
AD #: N/A
April 1980

This symposium, sponsored by the U.S. Army Chemical Systems Laboratory, ARRADCOM, was held during April 22 through 24, 1980 in Columbus, Ohio. The symposium includes four areas: detection (warning/alarms, identification, and monitoring); contamination control (contamination avoidance and decontamination); physical protection (individual and collective); medical aspects (prophylaxis and therapy).

25. Chemical Warfare Capabilities--Warsaw Pact Countries
J. Kenneth Crelling
AD-B041660
October 1979

This review assembles the unclassified information available on the chemical warfare posture of the Warsaw Pact countries, primarily the Soviet Union. Although chemical warfare agents were not used in World War II, new agents, the G-type nerve agents, had been developed by the Germans and manufacturing plants had been built. During Germany's collapse in 1944 and 1945, the Soviets captured some of these facilities, and transported them to Russia, and reportedly initiated production there.

From 1945 to the present, chemical warfare doctrine for Warsaw Pact countries has also become well established. Although it is not known in detail, adequate information exists to allow interpretation of potential offensive operations. While the Soviets unquestionably have the technology and capability to manufacture all types of chemical warfare agents, information on their stockpiles

appears to be mostly speculative, and size estimates range from several times to many times compared to stockpile ranges indicated for the United States. Among the chemical agents in their inventory, the Soviets have hydrogen cyanide, soman, thickened soman, and VR-55, the last believed by some authors to be another designated for thickened soman.

A full gamut of protective chemical-biological-radiological material is fielded by Warsaw Pact Armies, including protective masks and clothing and various collective protection systems, chemical agent detector-alarms and identification kits, individual decontamination kits, a wide variety of portable and vehicle-mounted decontamination equipment, including rapid-decontamination vehicles and personnel decontamination stations.

26. Environmental Temperature and the Percutaneous Absorption of A Cholinesterase Inhibitor, VX

F. N. Craig, E. G. Cummings, and V. M. Sim

AD #: N/A

1977

S-(2-diisopropylaminoethyl) o-ethyl methylphosphonothioate (VX), an anti-cholinesterase liquid of low volatility, was applied to the skin of 139 men at environmental temperatures -18°, 2°, 18°, or 46° C. The skin was decontaminated after 3 hr and the men spent the next 21 hr at about 27° C. The amount of VX penetrating the skin was estimated from the inhibition of red blood cell cholinesterase. The decimal fraction of the dose that penetrated in 3 hr ranged from 0.04 at -18° C to 0.029 at 46° C for the forearm. Further increase in cholinesterase inhibition after decontamination was evidence of a deposit of VX in the skin. The amount of VX remaining in the skin after decontamination was greater in the forearm and less in the cheek at higher temperatures.

27. Exploratory Development of a System for the Decontamination of Combat Vehicle Interiors

R. L. Brunel, D. C. Doerschuk, G. R. Riley, and C. V. Robinson

AD-B049679

June 1980

Battelle's Columbus Laboratories investigated several techniques for the large-scale decontamination of combat vehicle interiors. Tests involving the removal of the chemical agent simulant diethyl phthalate from a metal plate were conducted with four techniques: hot airflow, steam application, washing with detergent, and adsorption/vacuuming with diatomaceous earth and with Dutch powder. Steam application and hot airflow were determined to be the most effective of these techniques, and thus were tested on military vehicle interiors.

28. Study of Reactive Materials for Development of New Protective Clothing Concepts, A
Donald R. Cowsar, Danny H. Lewis, and Gary W. Whitehead
AD-A054877
January 1978

This report describes investigations of reactive materials suitable for incorporation in or on fabrics for protection from percutaneous chemical warfare agents. Microencapsulated forms of alkali metal hydroxides and aliphatic amines were developed and found to be unsuitable for protection from HD. Aqueous solutions of aliphatic amines containing 4-(N,N-dimethylamino) pyridine were found to destroy GB on contact. Microcapsules comprising granules of stabilized XXCC3 in ethyl cellulose walls were found to react readily with HD. These microcapsules were bonded to 8-oz sateen fabric with resin binders, and the permeation of HD vapor through the fabric was determined. At contamination densities of 2.4 mg/sq m the HD vapor penetration was found to be 6 μ g/sq cm. The treated fabrics were tested for stability toward washing and ultraviolet irradiation, and no change in agent vapor penetration was observed for either the washed samples or those subjected to irradiation for the equivalent of 1800 hours of sunlight.

29. Continued Investigation of Surface-Active Displacement Solutions/SADS II Detoxification and Application Data
A. E. Meyer, C. K. Akers, and R. W. King
AD #: N/A
3 September 1982

Two tasks were conducted for the project: (1) identification and preliminary survey of detoxification of chemical warfare agents; (2) decontaminant field application factors.

Fourteen types of detoxicants were identified through the literature search. However, when considering safety factors, only chloramine-T was chosen for malathion destruction test. At a 10:1 molar ratio of chloramine-T: malathion [chloramine-T was dissolved in a surface active displacement solution (SADS)], a greater than 99% destruction of the malathion in test solutions was observed at 5° C, 22° C, and 45° C. When chloramine-T-SADS was sprayed on painted aluminum panels that had been contaminated with malathion, it caused an average of 65% malathion destruction within 5 minutes.

It was recommended that a general application SADS spray unit includes a medium pressure, positive displacement pumping system. The unit should be made portable by incorporating a gasoline or diesel engine for power. The system pressure should be variable from several hundred psi to approximately 300 psi for cleaning and decontaminating substrates of various size and delicacy. An array of interchangeable nozzles used in conjunction with the variable pressure system could provide liquid flow rates from approximately one to ten gallons per minute. The high pressure/flow combination could be used on large objects that are heavily laden with dirt and debris, while more delicate surfaces will necessitate the use of lower pressure/flow combinations. High pressure hose (1/4 to 1/2-inch internal diameter), incorporating high pressure quick connectors, should be used for easily extending or breaking down the hose assembly. The handheld spray gun should be made of a durable material to withstand harsh use; its internal parts should be chemically resistant to the SADS components. Safety features such as a trigger lock and a comfort-designed handle should be incorporated. A "weep flow system" for low temperature freeze protection is also recommended.

30. Evaluation of Decontamination Formulations

Gary D. Sides, Edward B. Dismukes, and Ralph B. Spafford

Ad-A106385

July 1981

This report describes a research program that had as its central objective the development of a new water-based decontamination formulation effective against G-agents and mustard. Desired properties of the formulation included not only the rapid destruction of the three types of agents but noncorrosiveness, nontoxicity, economy with respect to consumption of chemical reagents, and logistical acceptability. The results of this research showed that micellar aldoximes (1-n-dodecyl-3-pyridinium/aldoximes salts) at a pH around 9.5 are good reagents for the nucleophilic destruction of GD and VX, but the data obtained in a parallel investigation by another contractor (INTERx Research Corporation Contract DAAK11-77-C-0098) indicated that these aldoximes are ineffective against mustard. A search for other nucleophilic reagents to detoxify mustards was unsuccessful. An evaluation of N-halo organic compounds, first as oxidative reactants for mustard, was then initiated. Ultimately, 3-N-bromo-4, 4-dimethyl-2-oxazolidinone in a buffer of approximately pH 9.5 was found to be the most promising compound evaluated. In a solution containing the surfactant cetyltrimethylammonium chloride in sufficient concentration to form micelles, this N-bromo compound was found to destroy mustard, GD, and VX with high effectiveness. The optimum composition of the decontamination formulation was not determined, but a test formulation 0.030 M in the N-bromo compound and 0.034 M in the surfactant yielded promising results. Although the N-bromo compound is an active halogen compound, its oxidation potential is well below those of inorganic hypohalites, and its corrosiveness is thus expected to be much less than that of aqueous bleach.

31. New Oxidants and Mechanisms of Oxidation

I. C. Popoff and R. Helitzer

AD-384208

June 1967

Agents HD, VX, BZ, GF and selected model compounds were permitted to react with the gaseous oxidants perchloryl fluoride, dinitrogen tetroxide, chlorine dioxide, and chlorine. VX and HD appeared to be susceptible to oxidant attack; whereas, BZ, if attacked at all, could usually be at least partly regenerated from salts formed in the process. GF was not attacked at all. The oxidation products were partially identified. Cotton cloth swatches and glass or metal surfaces contaminated with HD were decontaminated to a con-

siderable degree, when exposed for 60 min to sufficiently high concentrations of the gaseous oxidants. Cotton cloth swatches and glass surfaces contaminated with VX were decontaminated to the extent of 65% and 69%, respectively, when exposed for 30 min to perchlory fluoride. It was established that the enzymatic method is superior to the chromatographic method for establishing the degree of decontamination. Cloth swatches were not weakened by exposure to perchloryl fluoride or chlorine dioxide, but were significantly attacked by chlorine and dinitrogen tetroxide. Aluminum, stainless steel, magnesium, Plexiglas II, and neoprene were attacked with varying degrees of severity by gaseous oxidants on week-long exposures, especially at 50% (in contrast to 0%) relative humidity; attack by perchloryl fluoride was in almost every instance minimal. Thus, it would appear that perchloryl fluoride might be used to decontaminate materials contaminated with HD (and perhaps VX) without degrading the materials.

32. Decontamination of Surfaces Contaminated with Chemical Agents
Battelle Institute E. V. Frankfurt/Main
AD-B034759
July 1978

New P (V)-nucleophilic compounds were synthesized and subjected to a standardized test program. Of the water soluble compounds investigated, polyacrylamidoxime showed the highest reactivity with DFP. The product formed by reaction of chloroacetylhydroxylamines with alkyldimethylamines showed very good reactivity with DFP and paraoxon.

33. Phase I: A Feasibility Study on the Possible Development of Resin Polymer for the Filtering and Sensing of Chemical Agents
Donald R. Owen and John Jacobus
AD #: N/A
15 February 1979

This document discusses the following items:

- General biological and chemical properties of chemical warfare agents

- Review of polymeric chemicals and reactive polymeric materials
- Reactive polymeric matrices for chemical warfare agent removal. Two recommended approaches are mentioned: 1) active resin system to have the capability of reacting directly with chemical warfare agents; 2) active resin to catalytically hydrolyze war agents to less toxic compounds. Several copper chelates are proposed to be attached to polymeric substrates.
- Solid state agent detection systems

34. Study of Agent-Reactive Fabrics for Use in Protective Clothing, A
Gerald Zon
AD-A079940
December 1979

A broad investigation has been carried out to obtain modified fabrics which exhibit catalytic activity toward hydrolytic decomposition of chemical warfare agents. The major areas of study included the development of chemically modified Nomex and cotton-blend fabrics, mechanistic inquiries with regard to factors which control simulant/agent hydrolysis, and the design and construction of a suitable fabric testing apparatus for comparative evaluation of candidate fabrics.

35. Organophosphorus Pesticides: Organic and Biological Chemistry
Morifusa Eto
AD #: N/A
1974

In order to get a general concept of organophosphorus pesticides with such a variety in structure and biological activities, consideration of each aspect of chemistry, biochemistry, and the applied sciences is necessary. This book consists of these three main parts. After the presentation of the background of phosphorus chemistry in Chapter I, stress was put on the chemical and biochemical reactions of organophosphorus pesticides, including synthesis, analysis, metabolism mode of action, and other interesting aspects in

Chapter II to IV, and on the structure-pesticidal activity relationship in Chapter V. Almost all commercialized and important experimental organo-phosphorus pesticides are mentioned. Unlike insecticides, the mode of action of other pesticides is not well established, and the scattered knowledge about them is difficult to generalize. They are described in the corresponding sections of Chapter V, "Individual Pesticides." Although this book is designed as a readable text, it has reference value also.

36. Development of Package Decontaminating System (Final Report)
G. A. Richardson
AD-906245L
August 1972

The highly complex chemistry of DS-2 has been reasonably well resolved during this research program. This was essentially accomplished by (1) theoretically defining the primary function and/or functions of each of its components through mechanistic organic chemical theory and (2) by designed experiments which would either nullify or verify those theories.

The primary function and/or functions of each of the components in DS-2 are as follows: (1) diethylenetriamine serves as a strong chelating agent for the sodium ions; (2) methyl cellosolve serves as an extender for the amine, base and agent; in addition, it contributes to the formation of sodium 2-methoxyethoxide; (3) sodium hydroxide also contributes to the formation of sodium 2-methoxyethoxide which is the primary decontaminant in DS-2. Further, and of the utmost importance, diethylenetriamine and methyl cellosolve combine in a specific ratio to form an azeotropic mixture.

An attempt was made to improve DS-2's decontamination integrity (i.e., faster, ease of application, and less corrosive, etc.) by modifying the DS-2 formulation, but none of the substitute formulations was found to be markedly superior to DS-2.

37. Studies on the Destruction of Toxic Agents VX and HD by the All-Purpose Decontaminants DS-2 and CD-1
George T. Davis, Frank Block, Harold Z. Sommer, and Joseph Epstein
AD #: AD-A009708
May 1975

Kinetic evaluations were conducted of the efficiency of decontamination of agents HD [mustard:bis(-2-chloroethyl) sulfide] and VX [O-ethyl S-(diisopropyl-aminoethyl) methylphosphonothiolate] by the Army all-purpose decontaminant, DS-2 and the Air Force all-purpose decontaminant, CD-1. Some of the products have been isolated or identified. Spectrophotometric yields of the major product from HD decomposition by these decontaminants have been obtained.

38. Examination of Macrocyclic Ether-Alkali Metal Salt Complexes as Decontaminants for Chemical Warfare Agents in Non-Aqueous Solvents, An
A. A. Casselman, H. Gail Thompson, and R. A. B. Bannard
AD-A077516
October 1979

The feasibility of using macrocyclic ether--alkali metal salt complexes to effect the rapid destruction of the chemical warfare (CW) agents HD, GF, and VX at or near room temperature, in non-aqueous solvents has been examined. An investigation of the decontamination efficiency of complexes formed by the macrocyclic ethers, 15-crown-5, 18-crown-6 and cryptand [2.2.2] in conjunction with inorganic salts such as alkali hydroxides, potassium superoxide, potassium tert-butoxide, potassium dichromate and potassium acetate has been made. Agent destruction levels exceeding 80% were effected within 2 to 5 minutes at room temperature by several of the systems examined. Cryptand [2.2.2] was the most effective of the macrocyclic ethers in facilitating agent destruction. Generally, the relative ease of destruction of agents by the macrocyclic compounds followed the order HD > VX > GF. It is concluded that this new general approach to chemical decontamination is sufficiently promising to warrant further study by extension to other nucleophiles and cations.

39. Brief Review of the Chemistry of Crown Ethers, A
R.A.B. Bannard and A. A. Casselman
AD #: N/A
April 1976

This document briefly describes the following parameters of crown ethers.

- History
- Nomenclature
- Formation and stability of crown ether-metal ion complex
- Research and Application
- Physiological Property
- Synthesis method and isolation
- Analytical characters
- References

APPENDIX B
INDUSTRY TELEPHONE INQUIRIES

POLYMER SEARCH

Company	Address	Phone
American Cyanamid	Wayne, NJ	(201) 831-2000
American Polymers, Inc.	Patterson, NJ	(201) 697-1880
Amoco Chemical Corp.	Chicago, IL	(312) 856-3528
B. F. Goodrich	Cleveland, OH	(216) 447-6000
Cadillac Plastics and Chemical Co.	Birmingham, MI	(800) 521-4004
Casden Oil and Chemical	Dallas, TX	(214) 750-2800
Chemical Coating and Engineering Co.	Media, PA	(215) 566-7470
Dow Chemical Co.	Midland, MI	(800) 248-2345
Dupont De Nemours	Wilmington, DE	(302) 774-2421
Fiberfil Division	Evansville, IA	(812) 424-3831
H. B. Fuller Co.	St. Paul, MN	(800) 328-9673
Hercules, Inc.	Wilmington, DE	(302) 594-5000
Lab Safety Supply	Janesville, MI	(800) 356-0783
Minnesota Mining & Mfg. Corp. 3M Center	St. Paul, MN	(612) 733-0306
Minnesota Mining Mfg. Reg. Technical Rep.	Atlanta, GA	(404) 447-7132
Olin Corp. Chemical Division	Stamford, CT	(203) 356-2525
P. P. G. Industrial, Inc.	Pittsburgh, PA	(412) 434-2583
R. A. Chemical Corp.	New York, NY	(212) 859-2800
Richardson Technological Services	Madison, CT	(203) 245-0441
Rohm and Haas Co.	Philadelphia, PA	(215) 641-7000
Saltamer Co.	Westchester, PA	(215) 692-8400
Shell Chemical Co.	Houston, TX	(713) 241-6161
U. S. I. Chemicals	Dallas, TX	(214) 387-1130
Union Carbide	Atlanta, GA	(404) 633-6161
Uniroyal Chemical Co.	Naugatuck, CT	(203) 723-3849
Universal, Inc.	Kensington, CT	(203) 828-0335
Upjohn Polymer and Chemical Division	La Porte, TX	(713) 979-1541
Westlake Plastics Co.	Lenni, PA	(215) 459-1000

ADHESIVE SEARCH

Company	Address	Phone
Adell Plastics, Inc.	Baltimore, MD	(301) 789-7780
Allied Chemical Corp.	Morristown, NJ	(201) 455-2483
American Cyanamid	Wayne, NJ	(201) 831-2000
American Polymers, Inc.	Paterson, NJ	(201) 697-1880
Argus Co.	Brooklyn, NY	(212) 858-5678
Dow Chemical Co.	Midland, MI	(800) 248-2345
Dupont De Nemours	Wilmington, DE	(302) 774-2421
Durey Division of Hooker Chemicals	New York, NY	(716) 696-6234
Eastman Chemical Products	Kingsport, TN	(615) 247-0411
Emerson and Cuming	Canton, MA	(617) 828-3300
Fiberfil Division	Evansville, IA	(812) 424-3831
FMC Corp.	Princeton, NJ	(609) 452-2300
H. B. Fuller Co.	St. Paul, NM	(800) 328-9673
Hercules, Inc.	Wilmington, DE	(302) 594-5000
Montedison USA, Inc.	New York, NY	(212) 764-0260
Olin Corp. Chemical Division	Stamford, CT	(203) 356-2525
P. D. George Co.	St. Louis, MO	(314) 621-5700
P. P. G. Industrial, Inc.	Pittsburg, PA	(412) 434-2583
R. A. Chemical Corp.	New York, NY	(212) 859-2800
Rohm and Haas Co.	Philadelphia, PA	(215) 641-7000
Saltamer Co.	Westchester, PA	(215) 692-8400
3M Corp. 3M Center	St. Paul NM	(612) 733-0306
3M Regional Technical Rep.	Atlanta, GA	(404) 447-7132
Union Carbide	Atlanta, GA	(404) 633-6161
Universal Inc.	Kensington, CT	(203) 828-0335